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(12) **United States Patent**
Kozuma

(10) **Patent No.:** **US 9,055,245 B2**
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(54) **PHOTODETECTOR INCLUDING
DIFFERENCE DATA GENERATION CIRCUIT
AND DATA INPUT SELECTION CIRCUIT**

USPC 250/214 R, 214.1, 214 A, 214 LA;
327/514, 58-89; 257/290-294
See application file for complete search history.

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(JP)

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Intellectual Property Law Office, P.C.

(57) **ABSTRACT**

Adverse effects of noise are reduced. A photodetector circuit, a difference data generation circuit, and a data input selection circuit are included. The photodetector circuit has a function of generating an optical data signal. A first data signal and a second data signal is input to the difference data generation circuit and the difference data generation circuit has a function of generating difference data of data of the first data signal and data of the second data signal. The data input selection circuit has a function of determining that the data of optical data signal is regarded as data of the first data signal or data of the second data signal.

8 Claims, 9 Drawing Sheets

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 200 days.

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(52) **U.S. Cl.**

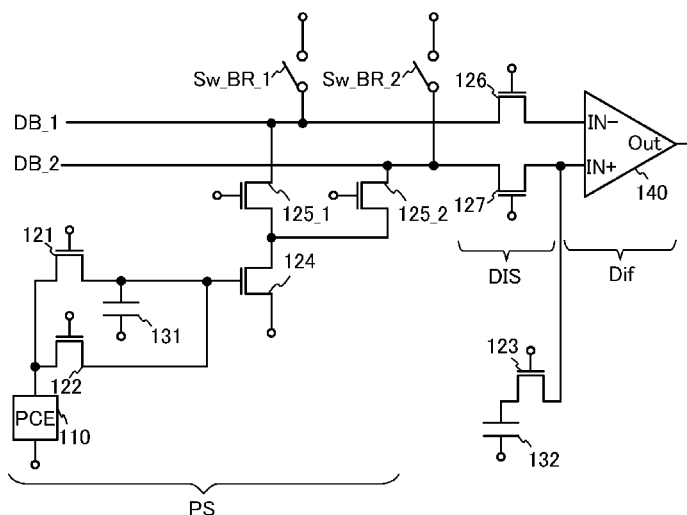
CPC **H04N 5/357** (2013.01); **H03F 3/08**

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(58) **Field of Classification Search**

CPC H04N 3/357; H04N 3/378; H04N 5/374



- (51) **Int. Cl.**
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FIG. 1A

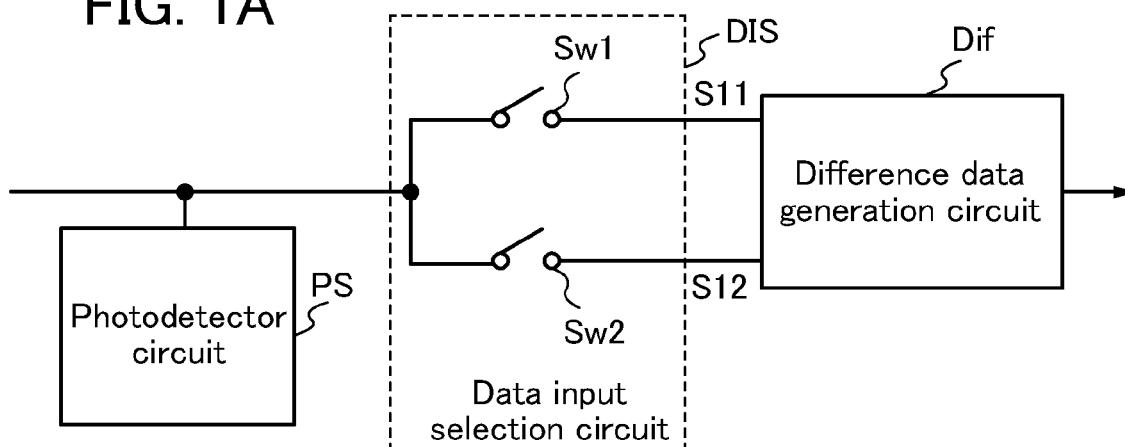
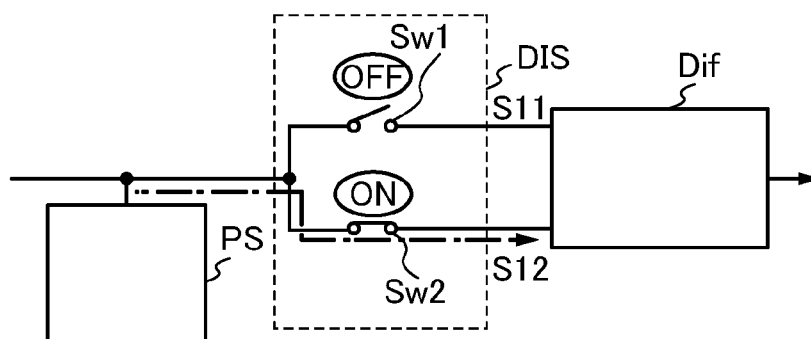


FIG. 1B-1

$D_PD=DA$



$D_PD=DB$

FIG. 1B-2

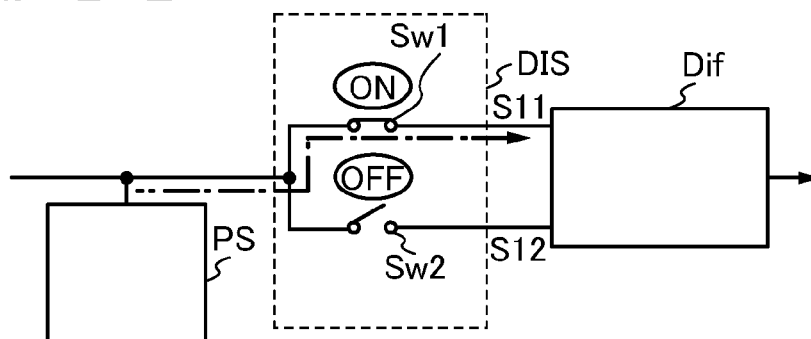


FIG. 2A

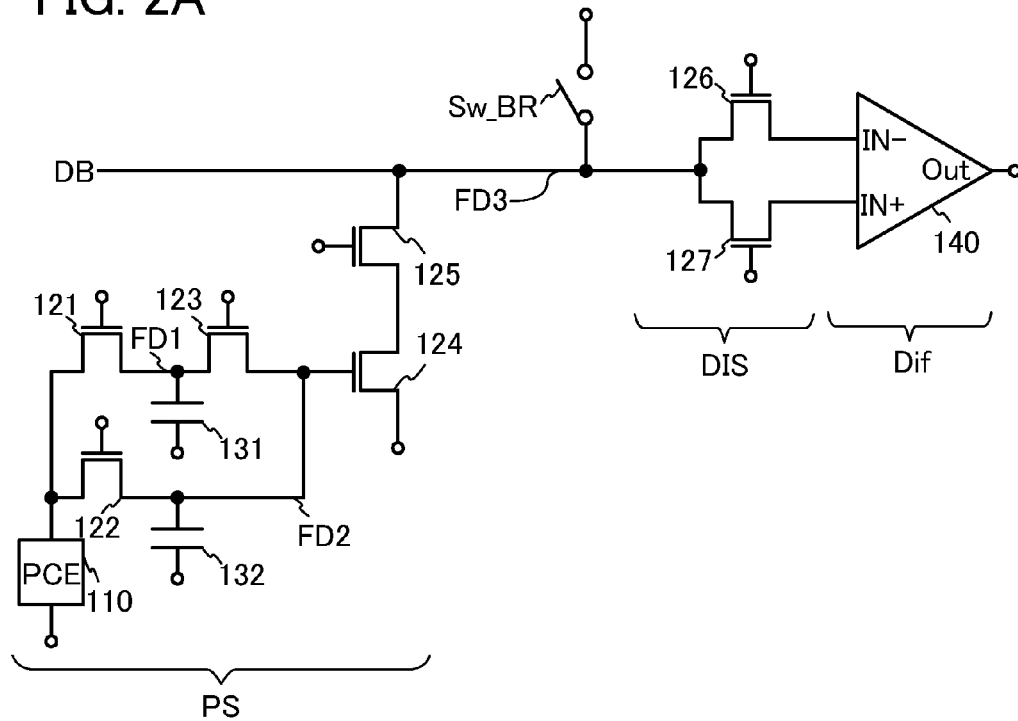


FIG. 2B

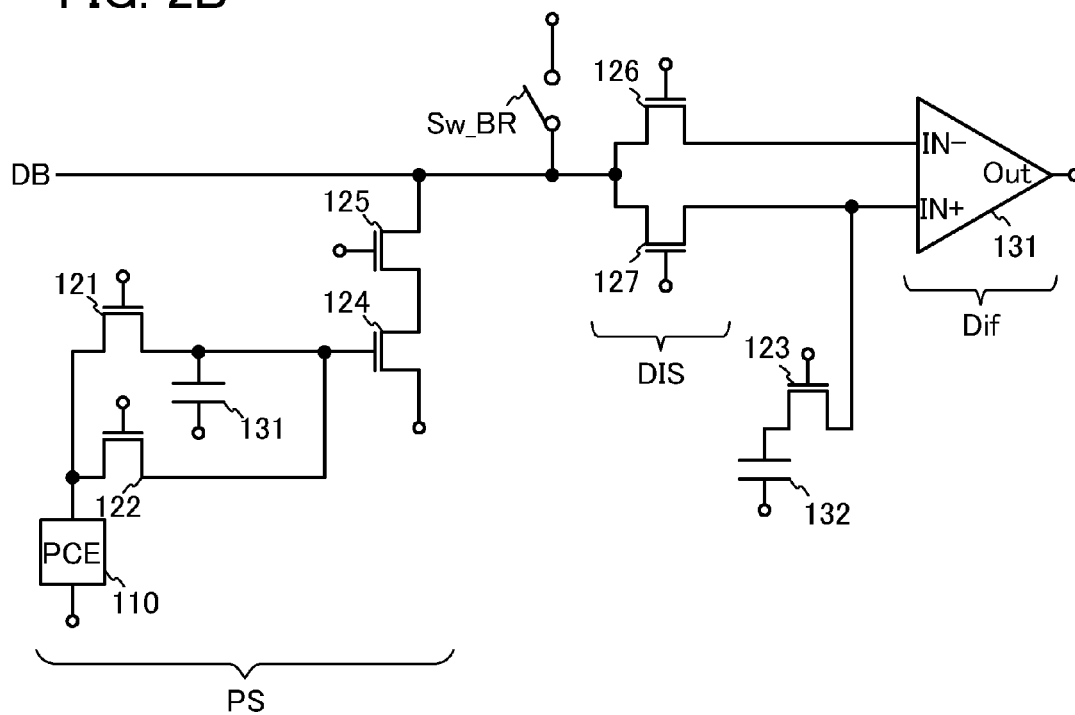


FIG. 3A

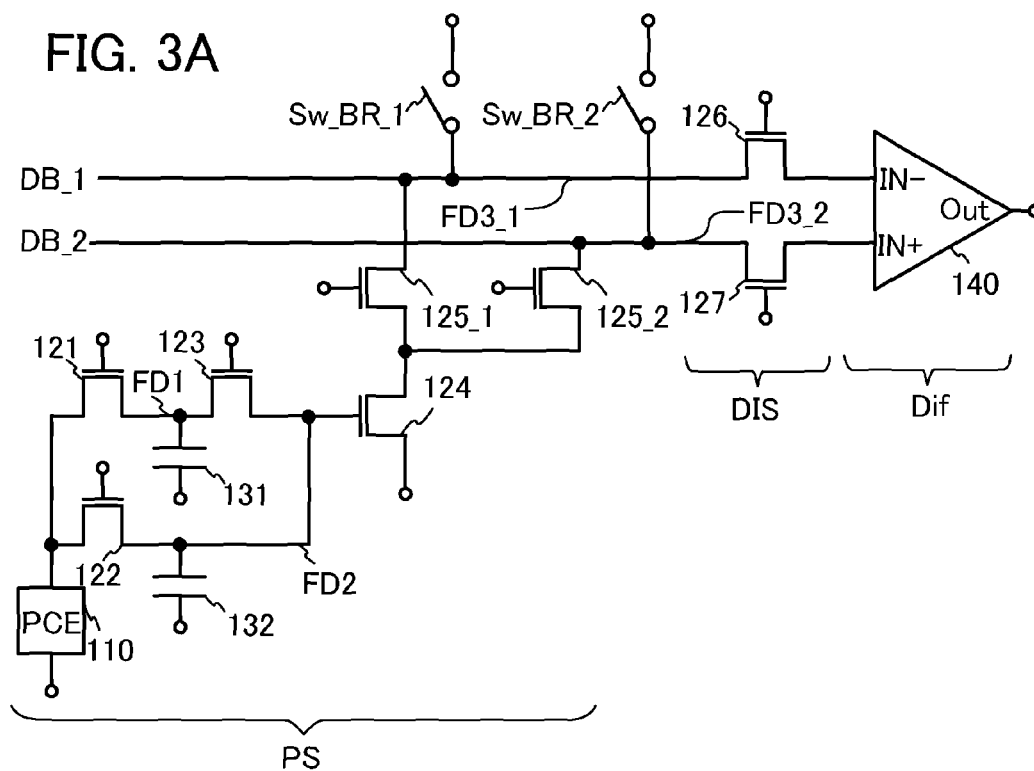


FIG. 3B

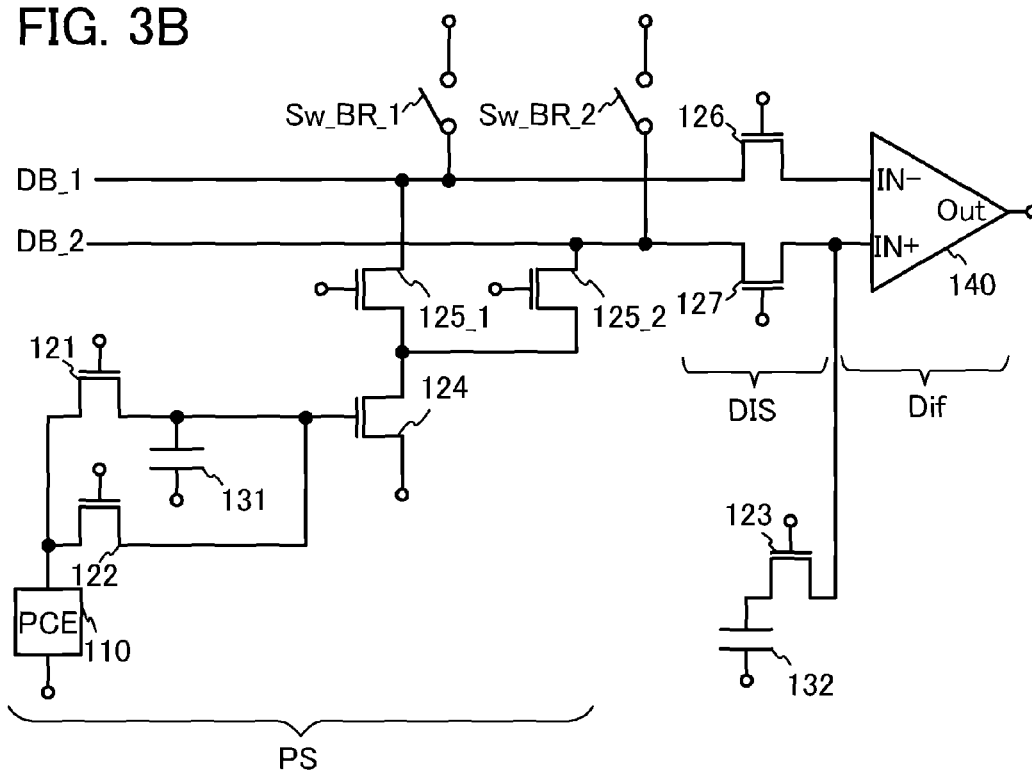


FIG. 4A

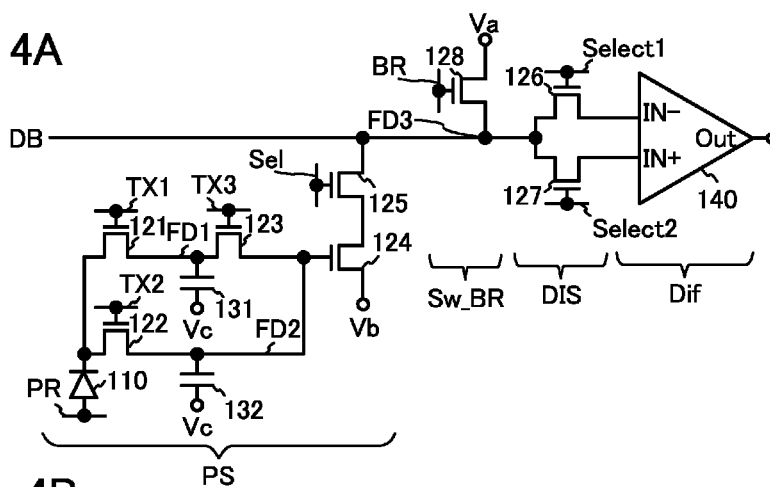


FIG. 4B

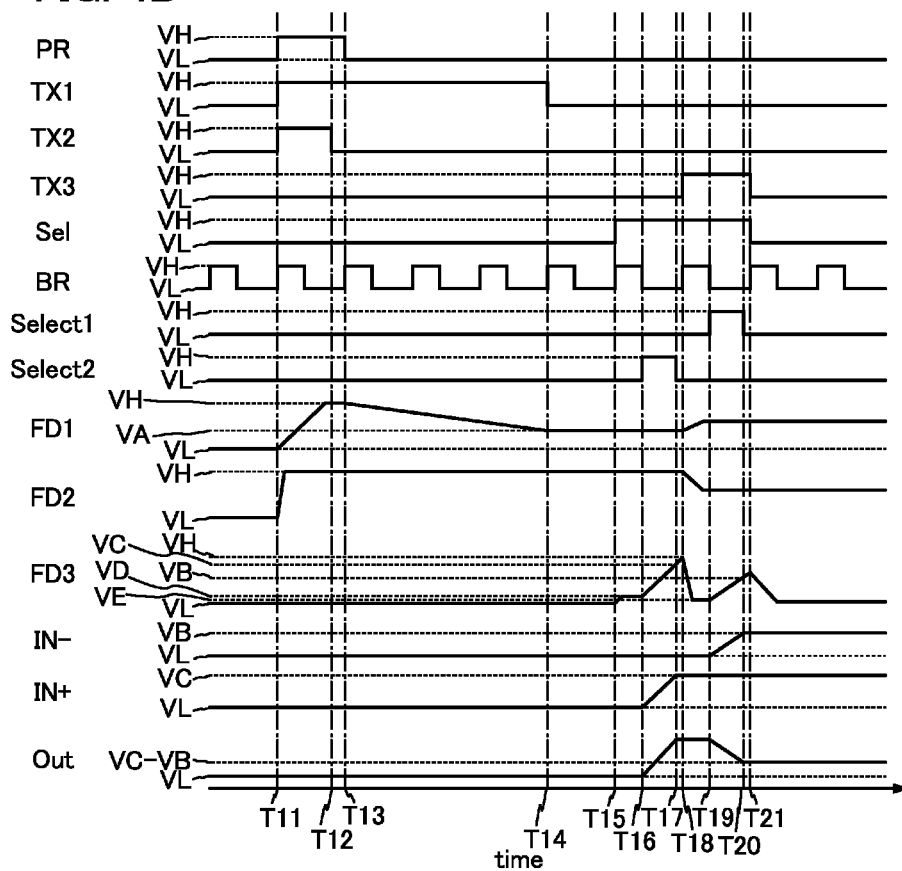


FIG. 5

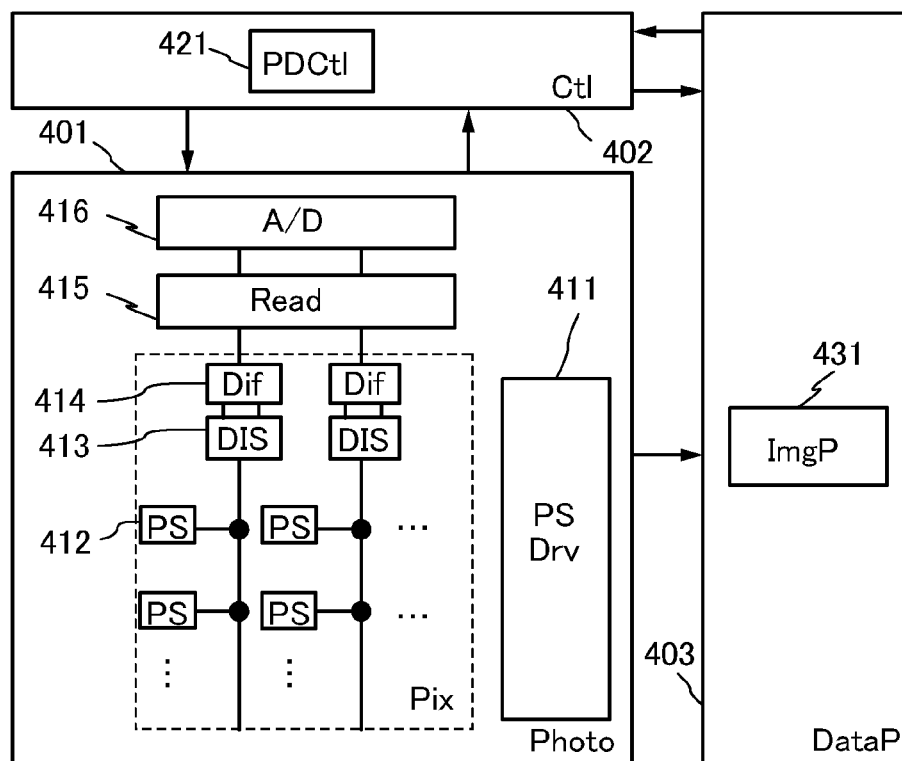


FIG. 6A

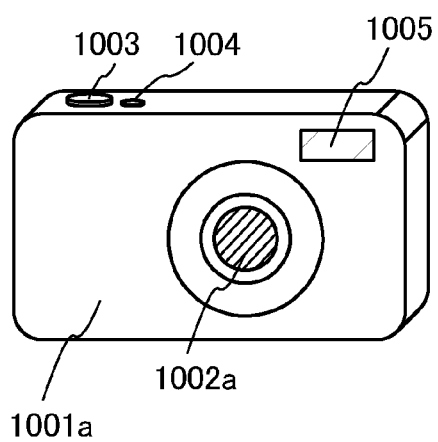


FIG. 6B

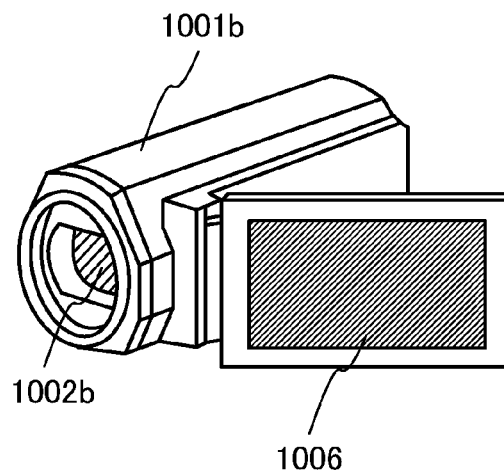


FIG. 7A

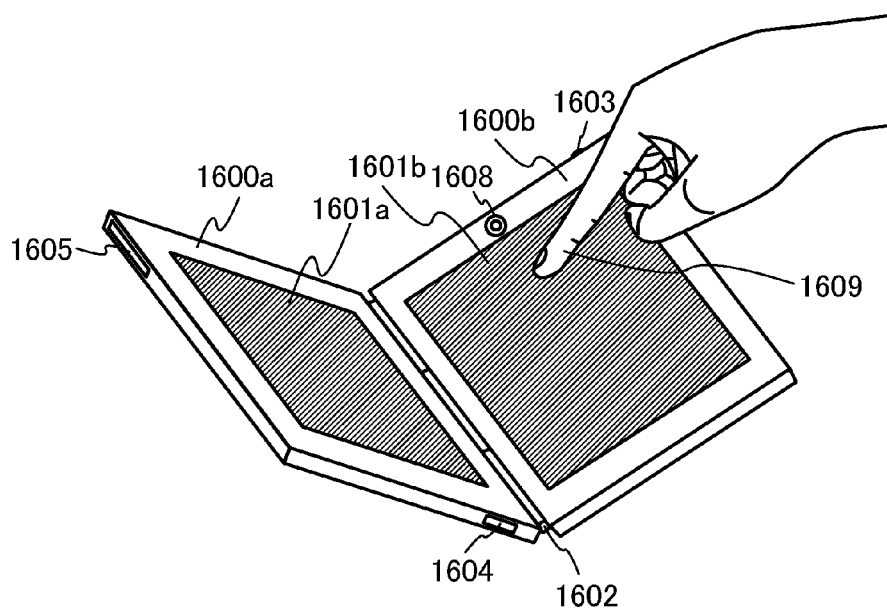


FIG. 7B

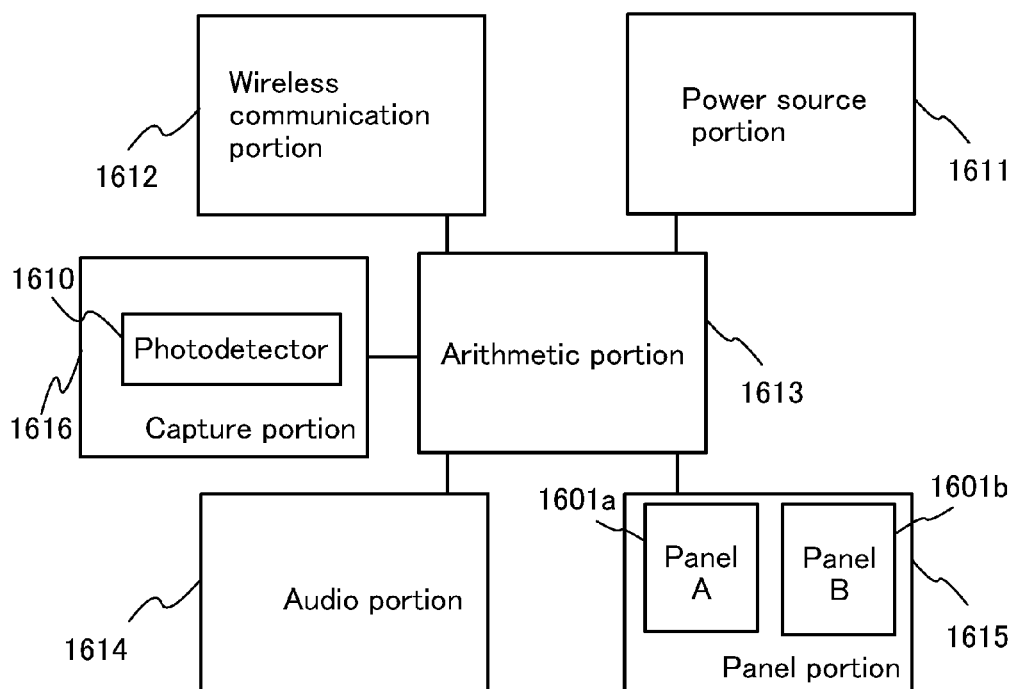


FIG. 8A

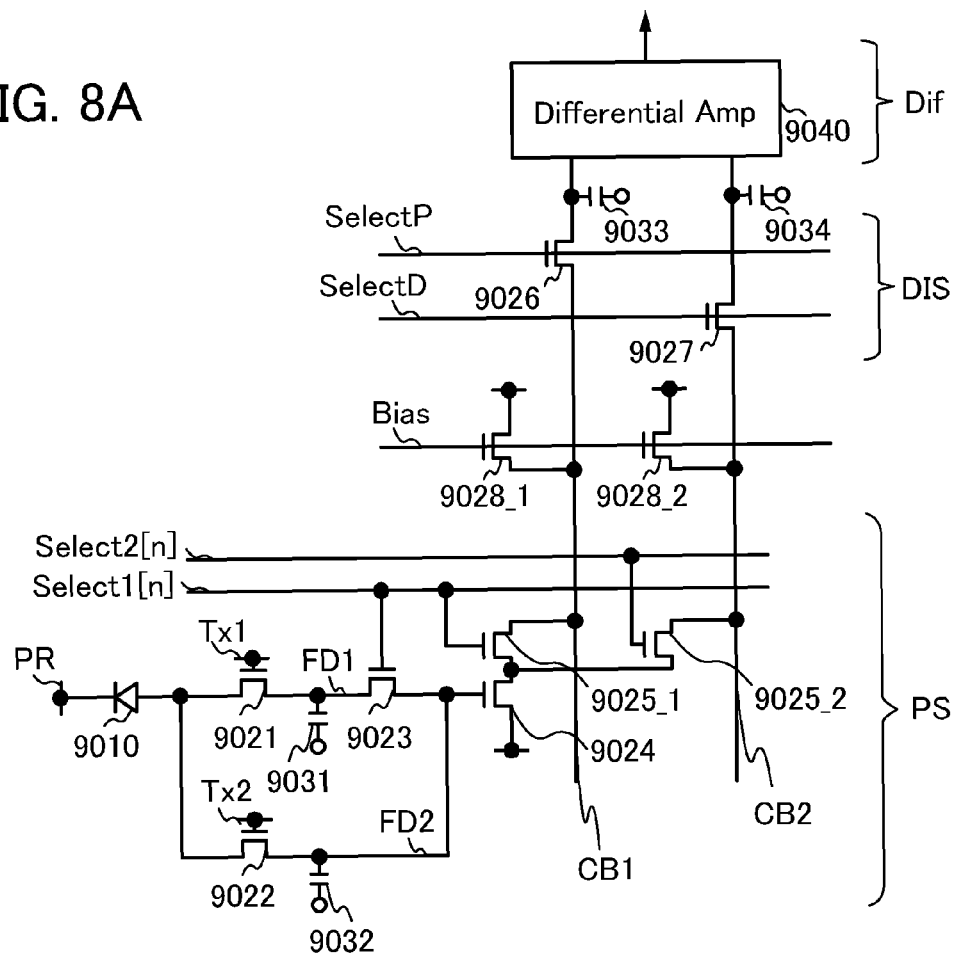


FIG. 8B

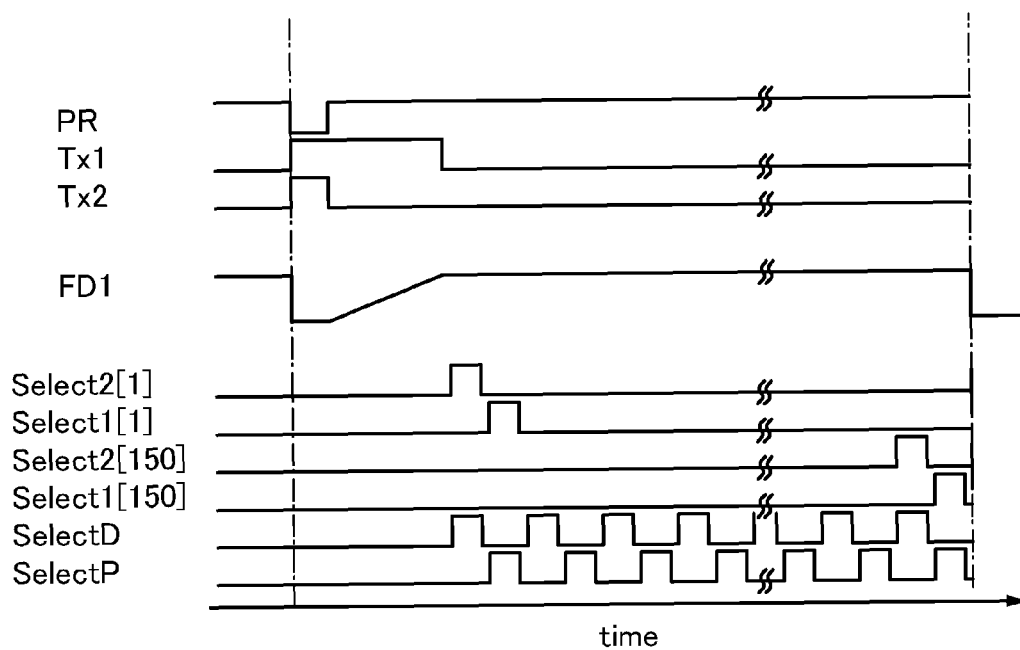


FIG. 9A

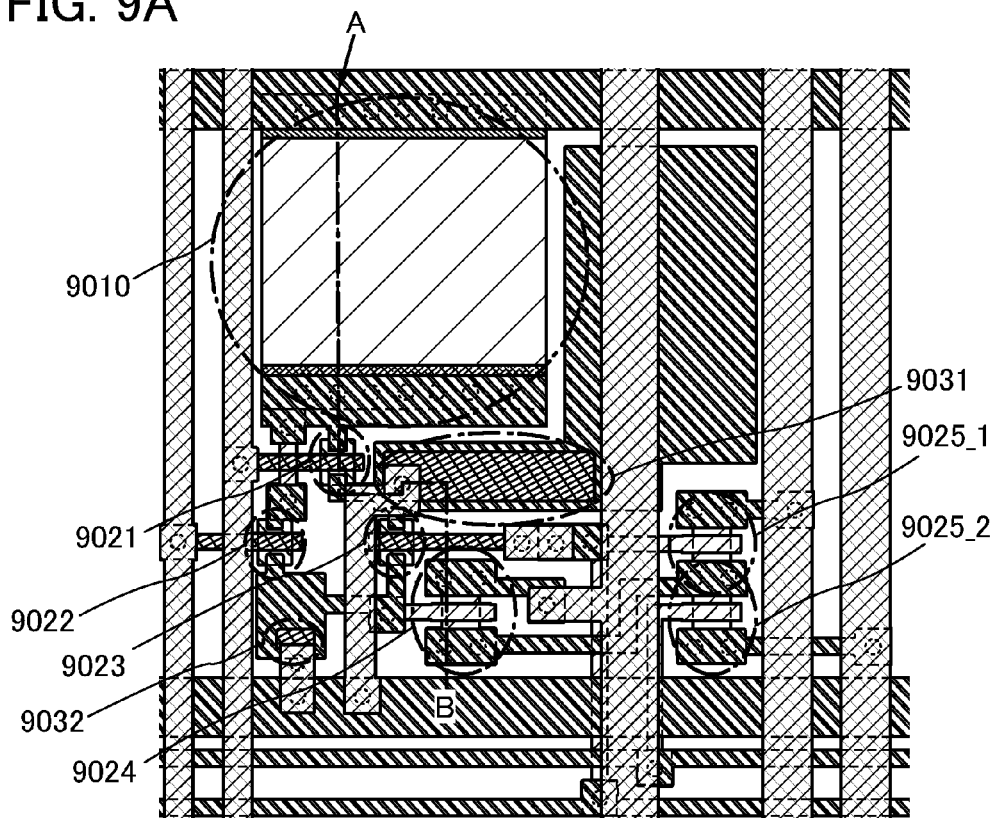
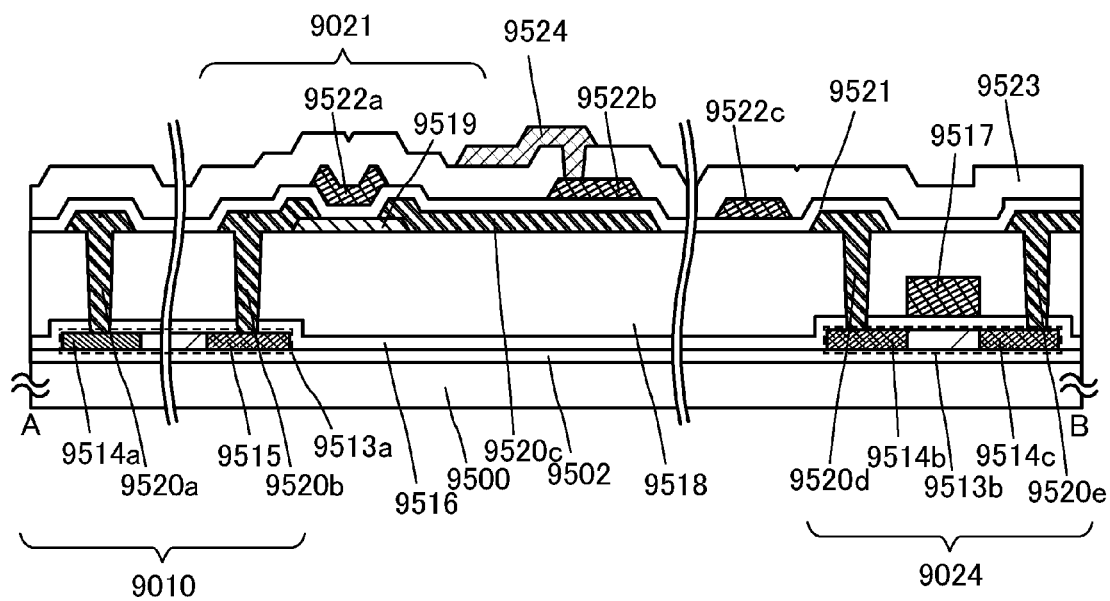


FIG. 9B



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PHOTODETECTOR INCLUDING DIFFERENCE DATA GENERATION CIRCUIT AND DATA INPUT SELECTION CIRCUIT

TECHNICAL FIELD

An embodiment of the present invention relates to a photodetector.

BACKGROUND ART

In recent years, technological development of a photodetector which inputs data with the use of a photodetector circuit (also referred to as an optical sensor) capable of generating data having a value corresponding to the illuminance of incident light, a photodetector which inputs data with the use of the photodetector circuit and outputs data in accordance with the input data, and the like has been advanced.

As an example of the photodetector, an image sensor can be given. As examples of the image sensor, a charge coupled device (CCD) image sensor, a complementary metal oxide semiconductor (CMOS) image sensor, and the like can be given (e.g., Patent Document 1).

As a driving system of CMOS image sensors, there are a rolling shutter system and a global shutter system. In a rolling shutter system, a plurality of photodetector circuits arranged in row and column directions are exposed to light row by row. In a global shutter system, photodetector circuits in all the rows are exposed to light at once.

REFERENCE

[Patent Document 1] Japanese Published Patent Application No. 2007-104186

DISCLOSURE OF INVENTION

However, conventional photodetectors have a problem of large variations of generated data due to noise, or the like. Examples of the noise are random noise and fixed pattern noise. As random noise, reset noise can be given, for example. Reset noise is included in an optical data signal generated by a photodetector circuit. The random noise is generated because of connection resistance between elements in a photodetector circuit, for example. Fixed pattern noise is generated because of variations in electrical characteristics of elements in a photodetector, for example.

For example, when the light-receiving area of a photodetector circuit in a photodetector is small, the amount of photocurrent generated in accordance with the amount of received light becomes smaller. Accordingly, the adverse effects of leakage current and noise become considerable, which makes it difficult to obtain correct data. To obtain data is also referred to as "capture data". For example, photodetectors mounted on small devices such as mobile phones become smaller and therefore the adverse effects of leakage current and noise, which affect the amount of received light, become a more serious problem.

It is an object of one embodiment of the present invention to reduce adverse effects of noise.

In one embodiment of the present invention, difference data of data of two periods that are different from each other and generated by a photodetector circuit. By generation of difference data, the amount of change due to noise is removed from the data.

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One embodiment of the present invention is a photodetector including a photodetector circuit, a difference data generation circuit, and a data input selection circuit.

The photodetector circuit has a function of generating an optical data signal.

A first data signal and a second data signal are input to the difference data generation circuit. In addition, the difference data generation circuit has a function of generating difference data of data of the first data signal and data of the second data signal.

The data input selection circuit has a function of determining that data of the optical data signal is regarded as the data of the first data signal or the data of the second data signal.

According to one embodiment of the present invention, the amount of change due to noise can be removed from generated data; therefore, the adverse effects of noise can be reduced.

BRIEF DESCRIPTION OF DRAWINGS

FIGS. 1A, 1B-1, and 1B-2 illustrate an example of a photodetector.

FIGS. 2A and 2B illustrate an example of a photodetector. FIGS. 3A and 3B illustrate an example of a photodetector. FIGS. 4A and 4B illustrate an example of a photodetector. FIG. 5 illustrates an example of a photodetector.

FIGS. 6A and 6B each illustrate an example of an electronic device.

FIGS. 7A and 7B each illustrate an example of an electronic device.

FIGS. 8A and 8B illustrate an example of a photodetector. FIGS. 9A and 9B illustrate an example of a photodetector.

BEST MODE FOR CARRYING OUT THE INVENTION

Examples of embodiments for describing the present invention will be explained below with reference to the drawings. Note that it will be readily appreciated by those skilled in the art that details of the embodiments can be modified in various ways without departing from the spirit and scope of the present invention. The present invention is therefore not limited to the following description of the embodiments.

Note that the contents in different embodiments can be combined with one another as appropriate. In addition, the contents of the embodiments can be replaced with each other as appropriate.

Further, the ordinal numbers such as "first" and "second" are used to avoid confusion between components and do not limit the number of each component.

Embodiment 1

In this embodiment, an example of a photodetector capable of generating difference data will be described with reference to FIGS. 1A, 1B-1, and 1B-2.

A photodetector illustrated in FIG. 1A includes a photodetector circuit PS, a difference data generation circuit Dif, and a data input selection circuit DIS.

The photodetector circuit PS has a function of generating an optical data signal. For example, data of an optical data signal obtained in a capture period corresponds to the illuminance of light entering the photodetector circuit (the amount of received light). A plurality of photodetector circuits may be provided in the photodetector.

The photodetector circuit PS includes a photoelectric conversion element and a field-effect transistor.

A data signal S11 and a data signal S12 are input to a first input terminal and a second input terminal of the difference data generation circuit Dif, respectively. The difference data generation circuit Dif has a function of generating difference data of data of the data signal S11 and data of the data signal S12.

The difference data generation circuit Dif includes a circuit with a function of performing a subtraction operation of the data of the data signal S11 and the data of the data signal S12. As the difference data generation circuit Dif, for example, a differential amplifier, a subtractor, or the like can be used.

The data input selection circuit DIS has a function of determining that data of the optical data signal generated by the photodetector circuit PS to be input to the difference data generation circuit Dif is regarded as the data of the data signal S11 or the data of the data signal S12.

The data input selection circuit DIS includes, for example, a switch Sw1 and the switch Sw2. The switch Sw1 has a function of determining whether or not the data of the optical data signal is input as the data of the data signal S11 to the difference data generation circuit Dif. The switch Sw2 has a function of determining whether or not the data of the optical data signal is input as the data of the data signal S12 to the difference data generation circuit Dif. Note that the switch Sw1 and the switch Sw2 each may be formed using a plurality of elements.

Next, as an example of a method for driving the photodetector of this embodiment, an example of a method for driving the photodetector illustrated in FIG. 1A will be described with reference to FIGS. 1B-1 and 1B-2.

In an example of a method for driving the photodetector illustrated in FIG. 1A, an optical data signal is generated by the photodetector circuit PS. At this time, when data of the optical data signal is data in a period TA, the data of the optical data signal (also referred to as D_PD) is DA (D_PD=DA). When the data of the optical data signal is data in a period TB, the data of the optical data signal (also referred to as D_PD) is DB (D_PD=DB). The period TA is, for example, a period in which the photodetector circuit PS is in a reset mode (also referred to as reset period). The period TB is a period in which the photodetector circuit PS is in a capture mode (also referred to as capture period).

In addition, common noise components are included in the data of the optical data signal that is DA and the data of the optical data signal that is DB.

When the data of the optical data signal is DA (D_PD=DA), as illustrated in FIG. 1B-1, the data input selection circuit DIS inputs the data of the optical data signal as data of the data signal S12 to the difference data generation circuit Dif. For example, the switch Sw2 is turned on and the switch Sw1 is turned off, whereby the data of the optical data signal can be input as the data of the data signal S12 to the difference data generation circuit Dif.

When the data of the optical data signal is DB (D_PD=DB), as illustrated in FIG. 1B-2, the data input selection circuit DIS inputs the data of the optical data signal as data of the data signal S11 to the difference data generation circuit Dif. For example, the switch Sw1 is turned on and the switch Sw2 is turned off, whereby the data of the optical data signal can be input as the data of the data signal S11 to the difference data generation circuit Dif.

The difference data generation circuit Dif generates difference data of the data of the data signal S11 and the data of the data signal S12. The amount of change corresponding to a common noise, which is included in the data of the data signal S11 (DB) and the data of the data signal S12 (DA), is removed from the generated difference data.

Further, the difference data generation circuit Dif outputs the generated difference data as a signal.

The above is the example of the method for driving the photodetector illustrated in FIG. 1A.

As described with reference to FIGS. 1A, 1B-1, and 1B-2, in an example of the photodetector in this embodiment, difference data of optical data signals are generated in a photodetector circuit in different two periods. Data of the optical data signals in two periods includes common noise components; therefore, the amount of change due to noise can be removed by generation of the difference data. Thus, adverse effects of noise can be reduced. In addition, the quality of a captured image can be improved. Note that the above method for removing the amount of change due to noise is also referred to as correlated double sampling (also referred to as CDS).

In an example of the photodetector of this embodiment, in accordance with the data of the optical data signal in the photodetector circuit, a data input selection circuit determines that the above data is regarded as data of a first data signal or as data of a second data signal. Since difference data can be generated by one kind of optical data signal with this structure, the number of elements in the photodetector circuit can be small. Accordingly, the aperture ratio of the photodetector can be improved.

Embodiment 2

In this embodiment, a configuration example of the photodetector described in Embodiment 1 will be explained with reference to FIGS. 2A and 2B, FIGS. 3A and 3B, and FIGS. 4A and 4B. Note that description of the part which is the same as the photodetector described in Embodiment 1 is skipped because the description of the photodetector described in Embodiment 1 can be referred to as appropriate.

A photodetector illustrated in FIG. 2A includes the photodetector circuit PS, the difference data generation circuit Dif, and the data input selection circuit DIS, like the photodetector illustrated in FIG. 1A. Further, the photodetector illustrated in FIG. 2A includes a data bus DB and a switch Sw_BR.

The photodetector circuit PS includes a photoelectric conversion element 110, field-effect transistors 121 to 125, and capacitors 131 and 132.

The photoelectric conversion element 110 includes a first current terminal and a second current terminal, and current (also referred to as photocurrent) flows between the first current terminal and the second current terminal in accordance with the illuminance of incident light.

A photodetection reset signal that is a pulse signal is input to the first current terminal of the photoelectric conversion element 110. A potential Vx that is a unit potential may be supplied to the first current terminal of the photoelectric conversion element 110.

The photoelectric conversion element 110 can be a photodiode, a phototransistor, or the like, for example. In the case of a photodiode, one of an anode and a cathode of the photodiode corresponds to the first current terminal of the photoelectric conversion element. In addition, the other of the anode and the cathode corresponds to the second current terminal of the photoelectric conversion element. In the case of a field-effect phototransistor, one of a source and a drain of the field-effect phototransistor corresponds to the first current terminal of the photoelectric conversion element. In addition, the other of the source and the drain of the field-effect phototransistor corresponds to the second current terminal of the

photoelectric conversion element. Note that the photoelectric conversion element **110** is not limited thereto and may be a bipolar phototransistor.

One of a source and a drain of the field-effect transistor **121** is connected to the second current terminal of the photoelectric conversion element **110**. A first charge transmission control signal that is a pulse signal is input to a gate of the field-effect transistor **121**. The field-effect transistor **121** has a function of controlling transmission of charge corresponding to the illuminance of light entering the photoelectric conversion element **110**. In this case, the transistor with such a function is also referred to as a charge transmission control transistor.

One of a source and a drain of the field-effect transistor **122** is connected to the second current terminal of the photoelectric conversion element **110**. A second charge transmission control signal that is a pulse signal is input to a gate of the field-effect transistor **122**. The field-effect transistor **122** has a function of controlling transmission of charge corresponding to the illuminance of light entering the photoelectric conversion element **110**.

One of a pair of electrodes of the capacitor **131** is electrically connected to the other of the source and the drain of the field-effect transistor **121**. A potential V_c is supplied to the other of the pair of electrodes of the capacitor **131**. The potential V_c is an arbitrary value. The capacitor **131** has a function as a first charge holding capacitor.

One of a pair of electrodes of the capacitor **132** is electrically connected to the other of the source and the drain of the field-effect transistor **122**. The potential V_c that is a unit potential is supplied to the other of the pair of electrodes of the capacitor **132**. The capacitor **132** has a function as a second charge holding capacitor.

One of a source and a drain of the field-effect transistor **123** is electrically connected to the other of the source and the drain of the field-effect transistor **121**. A third charge transmission control signal that is a pulse signal is input to a gate of the field-effect transistor **123**. Note that a connection portion of the one of the source and the drain of the field-effect transistor **123** and the other of the source and the drain of the field-effect transistor **121** is also referred to as the node **FD1**. The field-effect transistor **123** has a function of controlling transmission of charge corresponding to the illuminance of light entering the photoelectric conversion element **110**.

A potential V_b that is a unit potential is supplied to one of a source and a drain of the field-effect transistor **124**. A gate of the field-effect transistor **124** is electrically connected to the other of the source and the drain of the field-effect transistor **122** and the other of the source and the drain of the field-effect transistor **123**. Note that a connection portion of the gate of the field-effect transistor **124**, the other of the source and the drain of the field-effect transistor **122**, and the other of the source and the drain of the field-effect transistor **123** is also referred to as the node **FD2**. The potential of an optical data signal is set in accordance with current flowing between the source and the drain of the field-effect transistor **124**. The field-effect transistor **124** has a function of amplifying data corresponding to the photocurrent of the photoelectric conversion element **110**. A transistor with such a function is also referred to as an amplifying transistor.

One of a source and a drain of the field-effect transistor **125** is electrically connected to the other of the source and the drain of the field-effect transistor **124**. In addition, the other of the source and the drain of the field-effect transistor **125** is electrically connected to the data bus **DB**. Further, an output selection signal that is a pulse signal is input to a gate of the field-effect transistor **125**. The field-effect transistor **125** has

a function of determining whether or not an optical data signal generated by the photodetector circuit **PS** is output. A transistor with such a function is also referred to as an output selection transistor. Note that a connection portion of the other of the source and the drain of the field-effect transistor **125** and the data bus **DB** is also referred to as the node **FD3**.

The difference data generation circuit **Dif** includes a differential amplifier **140**.

The differential amplifier **140** includes a negative input terminal (also referred to as a terminal **IN-**), a positive input terminal (also referred to as a terminal **IN+**), and an output terminal (also referred to as the terminal **Out**). The differential amplifier **140** has a function of generating difference data of data of a signal input through the negative input terminal (the terminal **IN-**) and data of a signal input through the positive input terminal (the terminal **IN+**) and outputting a signal of a potential corresponding to the difference data through the output terminal (the terminal **Out**).

The data input selection circuit **DIS** includes a field-effect transistor **126** and a field-effect transistor **127**.

One of a source and a drain of the field-effect transistor **126** is electrically connected to the data bus **DB**. Accordingly, the one of the source and the drain of the field-effect transistor **126** is electrically connected to the other of the source and the drain of the field-effect transistor **125**. In addition, the other of the source and the drain of the field-effect transistor **126** is electrically connected to the negative input terminal of the differential amplifier **140**. Further, a first data input selection signal that is a pulse signal is input to a gate of the field-effect transistor **126**. The field-effect transistor **126** has a function of determining whether or not data is input to the difference data generation circuit **Dif**. A transistor with such a function is also referred to as a data input selection transistor.

One of a source and a drain of the field-effect transistor **127** is electrically connected to the data bus **DB**. Accordingly, the one of the source and the drain of the field-effect transistor **127** is electrically connected to the other of the source and the drain of the field-effect transistor **125**. In addition, the other of the source and the drain of the field-effect transistor **127** is electrically connected to the positive input terminal of the differential amplifier **140**. Further, a second data input selection signal that is a pulse signal is input to a gate of the field-effect transistor **127**. The field-effect transistor **127** has a function of selecting input of data to the difference data generation circuit **Dif**.

One or more of the field-effect transistors **121** to **127** can be field-effect transistors with low off-state current, for example. In this case, the off-state current per micrometer of channel width of the field-effect transistors **121** to **127** is 10 aA ($1 \times 10^{-17} \text{ A}$) or lower, preferably 1 aA ($1 \times 10^{-18} \text{ A}$) or lower, more preferably 10 zA ($1 \times 10^{-20} \text{ A}$) or lower, further preferably 1 zA ($1 \times 10^{-21} \text{ A}$) or lower, still further preferably 100 yA ($1 \times 10^{-22} \text{ A}$) or lower.

As the above field-effect transistor with low off-state current, it is possible to use a field-effect transistor including a semiconductor layer in which a channel is formed and which has a wider band gap than silicon, for example, 2 eV or more, preferably 2.5 eV or more, more preferably 3 eV or more. As the field-effect transistor having such a wide bandgap, a field-effect transistor including an oxide semiconductor layer in which a channel is formed can be used, for example.

As the oxide semiconductors layer, for example, an In-based oxide (e.g., indium oxide), a Sn-based oxide (e.g., tin oxide), and a Zn-based oxide (e.g., zinc oxide) can be given.

Alternatively, as the oxide semiconductor layer, a four-component metal oxide, a three-component metal oxide, or a two-component metal oxide may be used, for example. Note

that the oxide semiconductor layer may include gallium as a stabilizer for reducing variation in characteristics. A metal oxide which can be used as the above oxide semiconductor layer may include tin as a stabilizer. A metal oxide which can be used as the above oxide semiconductor layer may include hafnium as a stabilizer. A metal oxide which can be used as the above oxide semiconductor layer may include aluminum as a stabilizer. A metal oxide which can be used as the above oxide semiconductor layer may include one or more of the following material as a stabilizer: lanthanum, cerium, praseodymium, neodymium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium, which are lanthanoid. Further, the metal oxide that can be used as the oxide semiconductor layer may contain silicon oxide.

Examples of a four-component metal oxide are an In—Sn—Ga—Zn-based oxide, an In—Hf—Ga—Zn-based oxide, an In—Al—Ga—Zn-based oxide, an In—Sn—Al—Zn-based oxide, an In—Sn—Hf—Zn-based oxide, and an In—Hf—Al—Zn-based oxide.

Examples of the three-component metal oxide are an In—Ga—Zn-based oxide, an In—Sn—Zn-based oxide, an In—Al—Zn-based oxide, a Sn—Ga—Zn-based oxide, an Al—Ga—Zn-based oxide, a Sn—Al—Zn-based oxide, an In—Hf—Zn-based oxide, an In—La—Zn-based oxide, an In—Ce—Zn-based oxide, an In—Pr—Zn-based oxide, an In—Nd—Zn-based oxide, an In—Sm—Zn-based oxide, an In—Eu—Zn-based oxide, an In—Gd—Zn-based oxide, an In—Tb—Zn-based oxide, an In—Dy—Zn-based oxide, an In—Ho—Zn-based oxide, an In—Er—Zn-based oxide, an In—Tm—Zn-based oxide, an In—Yb—Zn-based oxide, and an In—Lu—Zn-based oxide.

Examples of a two-component metal oxide are an In—Zn-based oxide, a Sn—Zn-based oxide, an Al—Zn-based oxide, a Zn—Mg-based oxide, a Sn—Mg-based oxide, an In—Mg-based oxide, an In—Sn-based oxide, and an In—Ga-based oxide.

The oxide semiconductor layer may be an oxide semiconductor layer including CAAC-OS (c-axis aligned crystalline oxide semiconductor).

CAAC-OS is a mixed phase structure of a crystal region and an amorphous region. Further, in the crystal included in the crystal region, a c-axis is aligned in a direction perpendicular to a surface where the semiconductor layer is formed or a surface of the semiconductor layer, triangular or hexagonal atomic arrangement which is seen from the direction perpendicular to the a-b plane is formed, and metal atoms are arranged in a layered manner or metal atoms and oxygen atoms are arranged in a layered manner when seen from the direction perpendicular to the c-axis. Therefore, the CAAC-OS is not completely single crystal nor completely amorphous. Note that when the CAAC-OS includes a plurality of crystal regions, the directions of the a-axes and the b-axes of crystals of the plurality of crystal regions may be different from each other.

Note that in most cases, the crystal region of CAAC-OS fits inside a cube whose one side is less than 100 nm. From an observation image obtained with a transmission electron microscope (TEM), a boundary between a crystal region and an amorphous region in the CAAC-OS is not always clear. Further, a grain boundary in the CAAC-OS is not found. Thus, in the CAAC-OS, a reduction in electron mobility, due to the grain boundary, is prevented.

In the CAAC-OS, distribution of crystal regions is not necessarily uniform in the depth direction of the layer. For example, when a crystal growth occurs from a surface side of the semiconductor layer to form an oxide semiconductor

layer of CAAC-OS, in some cases, the proportion of the crystal portions in the vicinity of the surface of the oxide semiconductor layer in the CAAC-OS portion is high and the proportion of the amorphous portions in the vicinity of the surface where the oxide semiconductor layer in the CAAC-OS portion is formed is high.

Since the c-axes of the crystal included in the crystal region of the CAAC-OS are perpendicular to the surface where the oxide semiconductor layer in the CAAC-OS portion is formed or the surface of the oxide semiconductor layer in the CAAC-OS portion, the directions of the c-axes of the crystal portions may be different from each other depending on the shape of the oxide semiconductor layer in the CAAC-OS portion (the cross-sectional shape of the surface where the oxide semiconductor layer in the CAAC-OS portion is formed or the cross-sectional shape of the surface of the oxide semiconductor layer in the CAAC-OS portion). Note that the c-axes in the crystal regions of the CAAC-OS are substantially perpendicular to the surface where the oxide semiconductor layer in the CAAC-OS portion is formed or the surface of the oxide semiconductor layer in the CAAC-OS portion.

For example, the CAAC-OS can be formed by a sputtering method with a polycrystalline oxide semiconductor sputtering target. When ions collide with the sputtering target, a crystal region included in the sputtering target may be separated from the target along an a-b plane; in other words, a sputtered particle having a plane parallel to an a-b plane (flat-plate-like sputtered particle or pellet-like sputtered particle) may flake off from the sputtering target. In that case, the flat-plate-like sputtered particle reaches a substrate while maintaining their crystal state, whereby a crystal state of the sputtering target is transferred to a substrate. In this manner, the CAAC-OS is formed.

For the deposition of the CAAC-OS, the following conditions are preferably used.

For example, the CAAC-OS is formed while the impurity concentration is reduced, whereby the crystal state of the oxide semiconductor can be prevented from being broken by the impurities. For example, impurities (e.g., hydrogen, water, carbon dioxide, or nitrogen) which exist in the deposition chamber are preferably reduced. For example, a deposition gas whose dew point is -80°C . or lower, preferably -100°C . or lower is preferably used as a deposition gas.

By increasing the substrate heating temperature during the deposition, migration of a sputtered particle is likely to occur after the sputtered particle is attached to a substrate surface. Specifically, the substrate heating temperature during the deposition is higher than or equal to 100°C . and lower than or equal to 740°C ., preferably higher than or equal to 200°C . and lower than or equal to 500°C . By increasing the substrate heating temperature during the deposition, when the flat-plate-like sputtered particle reaches the substrate, migration occurs on the substrate surface, so that a flat plane of the flat-plate-like sputtered particle is attached to the substrate.

Furthermore, it is preferable that the proportion of oxygen in the deposition gas be increased and the power be optimized in order to reduce plasma damage at the deposition. The proportion of oxygen in the deposition gas is 30 vol % or higher, preferably 100 vol %.

As an example of the sputtering target, an In—Ga—Zn—O compound target is described below.

The In—Ga—Zn—O compound target, which is polycrystalline, is made by mixing InO_X powder, GaO_Y powder, and ZnO_Z powder in a predetermined ratio, applying pressure, and performing heat treatment at a temperature higher than or equal to 1000°C . and lower than or equal to 1500°C . Note that X, Y, and Z are each a given positive number. Here, the

predetermined ratio of InO_x powder to GaO_y powder and ZnO_z powder is, for example, 2:2:1, 8:4:3, 3:1:1, 1:1:1, 4:2:3, or 3:1:2. The kinds of powder and the molar ratio for mixing powder may be determined as appropriate depending on the desired sputtering target.

With an oxide semiconductor layer including CAAC-OS in the semiconductor layer of the field-effect transistor in which a channel is formed, fluctuation in electric characteristics of the field-effect transistor due to irradiation with visible light or ultraviolet light can be suppressed and the reliability of the field-effect transistor can be improved.

Further, the field-effect transistors 121 to 127 may be field-effect transistors with different characteristics from each other.

The photodetector may be provided with a light blocking layer that blocks light entering the field-effect transistors 121 to 127. With the light blocking layer, variations in electrical characteristics of the field-effect transistors can be suppressed.

The data bus DB has a function of transmitting data of an optical data signal, which is generated by the photodetector circuit PS.

A switch Sw_BR has a function of determining whether or not the data bus DB is reset. Note that the switch Sw_BR is formed by using a plurality of elements.

The photodetector illustrated in FIG. 2B is different from the photodetector illustrated in FIG. 2A in a connection relation of the field-effect transistor 123 and a connection relation of the capacitor 131.

In the photodetector illustrated in FIG. 2B, the field-effect transistor 123 and the capacitor 132 are provided in a part which is not the photodetector circuit PS. The one of the source and the drain of the field-effect transistor 123 is electrically connected to the other of the source and the drain of the field-effect transistor 127. The one of the pair of electrodes of the capacitor 132 is electrically connected to the other of the source and the drain of the field-effect transistor 123. The potential Vc is supplied to the other of the pair of electrodes of the capacitor 132. The gate of the field-effect transistor 124 is electrically connected to the other of the source and the drain of the field-effect transistor 121 and the other of the source and the drain of the field-effect transistor 122.

A photodetector illustrated in FIG. 3A includes a field-effect transistor 125_1 and a field-effect transistor 125_2 instead of the field-effect transistor 125 of the photodetector illustrated in FIG. 2A. A photodetector illustrated in FIG. 3B includes the field-effect transistor 125_1 and the field-effect transistor 125_2 instead of the field-effect transistor 125 of the photodetector illustrated in FIG. 2B.

At this time, the photodetector further includes a data bus DB_1 and a data bus DB_2 instead of the data bus DB. Furthermore, instead of the switch Sw_BR, the photodetector includes a switch Sw_BR1 for determining whether or not the data bus DB_1 is reset and a switch Sw_BR2 for determining whether or not the data bus DB_2 is reset.

One of a source and a drain of the field-effect transistor 125_1 and one of a source and a drain of the field-effect transistor 125_2 are electrically connected to the one of the source and the drain of the field-effect transistor 124. Further, the other of the source and the drain of the field-effect transistor 125_1 is electrically connected to the data bus DB_1. The other of the source and the drain of the field-effect transistor 125_2 is electrically connected to the data bus DB_2. The one of the source and the drain of the field-effect transistor 126 is electrically connected to the data bus DB_1. The one of the source and the drain of the field-effect transistor

127 is electrically connected to the data bus DB_2. A connection portion of the other of the source and the drain of the field-effect transistor 125_1 and the data bus DB_1 is also referred to as the node FD3_1. A connection portion of the other of the source and the drain of the field-effect transistor 125_2 and the data bus DB_2 is also referred to as the node FD3_2.

Next, as an example of a method of driving photodetector of this embodiment, an example of a method of driving a photodetector in FIG. 4A will be described with reference to a timing chart shown in FIG. 4B. In the case of the photodetector illustrated in FIG. 4A, the photoelectric conversion element 110 in the photodetector illustrated in FIG. 2A is a photodiode, the switch Sw_BR is a field-effect transistor 128, and the field-effect transistors 121 to 128 are n-channel transistors.

At this time, the anode of the photodiode, which is the photoelectric conversion element 110, is electrically connected to a photodetection reset signal line PR for inputting a photodetection reset signal.

The one of the source and the drain of the field-effect transistor 121 is electrically connected to the cathode of the photoelectric conversion element 110. The gate of the field-effect transistor 121 is electrically connected to a first charge transmission control signal line TX1 for inputting a first charge transmission control signal.

The one of the source and the drain of the field-effect transistor 122 is electrically connected to the cathode of the photoelectric conversion element 110. The gate of the field-effect transistor 122 is electrically connected to a second charge transmission control signal line TX2 for inputting a second charge transmission control signal.

The gate of the field-effect transistor 123 is electrically connected to a third charge transmission control signal line TX3 for inputting the third charge transmission control signal.

The gate of the field-effect transistor 125 is electrically connected to an output selection signal line Sel for inputting an output selection signal.

The gate of the field-effect transistor 126 is electrically connected to a first data input selection signal line Select1 for inputting a first data input selection signal.

The gate of the field-effect transistor 127 is electrically connected to a second data input selection signal line Select2 for inputting a second data input selection signal.

A potential Va that is a unit potential is supplied to one of a source and a drain of the field-effect transistor 128. The other of the source and the drain of the field-effect transistor 128 is electrically connected to the data bus DB. A gate of the field-effect transistor 128 is electrically connected to a bus reset signal line BR for inputting a bus reset signal.

The potential Va, the potential Vb, and the potential Vc are a low-level potential, a high-level potential, and a ground potential, respectively. The high-level potential is equal or substantially equal to a high-level potential of a binary digital signal. The low-level potential is equal or substantially equal to a low-level potential of a binary digital signal. The low-level potential is equal or substantially equal to a ground potential.

Whenever the potential of the bus reset signal line BR becomes high, the data bus DB is reset.

In an example of a method of driving the photodetector illustrated in FIG. 4A, as illustrated in FIG. 4B, in a time T11 (also referred to as a reset operation start time), the photodetection reset signal line PR, the first charge transmission control signal line TX1, and the second charge transmission control signal line TX2 are made to have a high-level poten-

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tial (also referred to as VH); and the third charge transmission control signal line TX3, the output selection signal line Sel, the first data input selection signal line Select1, and the second data input selection signal line Select2 are made to have a low-level potential (also referred to as VL).

In this case, when the photoelectric conversion element 110 is forward-biased, charge is accumulated in the capacitor 131 and the capacitor 132; therefore, the potentials of the node FD1 and the node FD2 are equal or substantially equal to a high-level potential. As a result, the photodetector circuit PS is in a reset mode.

Next, in a time T12 (also referred to as a reset operation completion time), the second charge transmission control signal line TX2 is made to have a low-level potential. The photodetection reset signal line PR and the first charge transmission control signal line TX1 hold the high-level potential. The third charge transmission control signal line TX3, the output selection signal line Sel, the first data input selection signal line Select1, and the second data input selection signal line Select2 hold a low-level potential.

In this case, the node FD2 becomes a floating state, and the potential of the node FD2 is held at a level equal or substantially equal to that of a high-level potential.

Next, in a time T13 (also referred to as a capture operation start time), the photodetection reset signal line PR is made to have a low-level potential. The first charge transmission control signal line TX1 holds the high-level potential. The second charge transmission control signal line TX2, the third charge transmission control signal line TX3, the output selection signal line Sel, the first data input selection signal line Select1, and the second data input selection signal line Select2 hold the low-level potential.

In that case, the photoelectric conversion element 110 is reverse-biased. Accordingly, photocurrent is generated in the photoelectric conversion element 110 on the basis of the illuminance of incident light. In addition, the charge accumulated in the capacitor 131 is lost in accordance with the photocurrent. On the other hand, since the second charge transmission control signal line TX2 holds the low-level potential, charge in the capacitor 132 is held. As a result, the photodetector circuit PS is in a capture mode.

Next, in a time T14 (also referred to as a capture operation completion time), the first charge transmission control signal line TX1 is made to have a low-level potential. Note that the photodetection reset signal line PR, the second charge transmission control signal line TX2, the third charge transmission control signal line TX3, the output selection signal line Sel, the first data input selection signal line Select1, and the second data input selection signal line Select2 hold the low-level potential.

In this case, capture operation is completed. In addition, the photocurrent allows the potential of the node FD1 to be VA. The value of VA depends on the photocurrent of the photoelectric conversion element 110. Note that the potential of the node FD2 is kept to be equal or substantially equal to a high-level potential.

Note that when the photodetector circuit in this embodiment is driven in a plurality of frame periods, data of an optical data signal of the photodetector circuit in a reset mode and data of an optical data signal of the photodetector circuit in a capture mode include common noise components during a time from a reset start time of a frame period to a reset start time of the next frame period.

Next, in a time T15 (also referred to as a photodetector circuit selection operation start time), the output selection signal line Sel and the bus reset signal line BR are made to have a high-level potential. Note that the photodetection reset

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signal line PR, the first charge transmission control signal line TX1, the second charge transmission control signal line TX2, the third charge transmission control signal line TX3, the first data input selection signal line Select1, and the second data input selection signal line Select2 hold the low-level potential.

At this time, the potential of the node FD3 becomes VD. VD depends on each channel resistance of the field-effect transistor 124, the field-effect transistor 125, and the field-effect transistor 128, and wiring resistance. VD is higher than Va and lower than Vb.

Next, in a time T16 (also referred to as a first selection operation start time), the bus reset signal line BR is made to have a low-level potential and the second data input selection signal line Select2 is made to have a high-level potential. Note that the output selection signal line Sel holds the high-level potential. The photodetection reset signal line PR, the first charge transmission control signal line TX1, the second charge transmission control signal line TX2, the third charge transmission control signal line TX3, and the first data input selection signal line Select1 hold the low-level potential.

In this case, the potential of the node FD3 and the potential of the positive input terminal (the terminal IN+) of the differential amplifier 140 are changed. After that, the potential of the node FD3 and the potential of the positive input terminal (the terminal IN+) of the differential amplifier 140 become VC. VC corresponds to the value of current flowing between the source and the drain of the field-effect transistor 124. That is, the potential of the positive input terminal (the terminal IN+) of the differential amplifier 140 corresponds to the potential of the gate of the field-effect transistor 124; therefore, the potential of the positive input terminal (the terminal IN+) corresponds to the potential of the gate of the field-effect transistor 124 in a reset mode.

Next, in a time T17 (a first selection operation completion time), the second data input selection signal line Select2 is made to have a low-level potential. Note that the output selection signal line Sel holds the high-level potential. The photodetection reset signal line PR, the first charge transmission control signal line TX1, the second charge transmission control signal line TX2, the third charge transmission control signal line TX3, and the first data input selection signal line Select1 hold the low-level potential.

In this case, the potential of the positive input terminal (the terminal IN+) of the differential amplifier 140 is kept at VC. On the other hand, the potential of the node FD3 keeps increasing until the next reset operation of the data bus DB is performed. The maximum potential of the node FD3 at this time is VH.

Next, in a time T18 (also referred to as a capture data read operation start time), the third charge transmission control signal line TX3 and the bus reset signal line BR are made to have a high-level potential. Note that the output selection signal line Sel holds the high-level potential. The photodetection reset signal line PR, the first charge transmission control signal line TX1, the second charge transmission control signal line TX2, the first data input selection signal line Select1, and the second data input selection signal line Select2 hold the low-level potential.

At this time, the node FD1 and the node FD2 become a conduction state. The potential of the node FD1 (FD2) is $(C131/C131+C132) \times VFD1 + (C132/C131+C132) \times VFD2$. Note that VFD1 is the potential of the node FD1 after the first charge transmission control signal line TX1 is made to have a low-level potential and before the node FD1 is in conduction with the node FD2 (the potential of the node FD1 from the time T14 to the time T18), and VFD2 is the potential of the

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node FD2 after the first charge transmission control signal line TX1 is made to have a low-level potential and before the node FD2 is in conduction with the node FD1 (the potential of the node FD2 from the time T14 to the time T18). In this manner, the potential of the node depends on a ratio of the capacitance of the capacitor 131 to the capacitance of the capacitor 132. For example, in order that at this time the potential of the node FD1 (FD2) be closer to the potential of the node FD1 after the first charge transmission control signal line TX1 is made to have a low-level potential and before the node FD1 is in conduction with the node FD2 (the potential of the node FD1 from the time T14 to the time T18), the capacitance of the capacitor 131 is made to be larger than the capacitance of the capacitor 132.

In a time T18, the potential of the node FD3 becomes VE. In this case, VE is lower than VC.

Next, in a time T19 (also referred to as a second selection operation start time), the bus reset signal line BR is made to have a low-level potential and the first data input selection signal line Select1 is made to have a high-level potential. Note that the third charge transmission control signal line TX3 and the output selection signal line Sel hold the high-level potential. The photodetection reset signal line PR, the first charge transmission control signal line TX1, the second charge transmission control signal line TX2, and the second data input selection signal line Select2 hold the low-level potential.

At this time, the potential of the node FD3 and the potential of the negative input terminal (the terminal IN-) of the differential amplifier 140 are changed. After that, the potential of the node FD3 and the potential of the negative input terminal (the terminal IN-) of the differential amplifier 140 become VB. VB corresponds to the value of current flowing between the source and the drain of the field-effect transistor 124. That is, the potential of the negative input terminal (the terminal IN-) corresponds to the potential of the gate of the field-effect transistor 124; therefore, the potential of the negative input terminal (the terminal IN-) corresponds to the illuminance of light entering the photoelectric conversion element 110.

Next, in a time T20 (also referred to as a second selection operation completion time), the first data input selection signal line Select1 is made to be a low-level potential. Note that the third charge transmission control signal line TX3 and the output selection signal line Sel hold the high-level potential. The bus reset signal line BR, the photodetection reset signal line PR, the first charge transmission control signal line TX1, the second charge transmission control signal line TX2, and the second data input selection signal line Select2 hold the low-level potential.

In this case, the potential of the negative input terminal (the terminal IN-) of the differential amplifier 140 is kept at VB. On the other hand, the potential of the node FD3 keeps increasing until the next reset operation of the data bus DB is performed. The maximum potential of the node FD3 at that time is VH.

Next, in a time T21 (also referred to as a photodetector circuit selection operation completion time), the bus reset signal line BR is made to have a high-level potential, and the third charge transmission control signal line TX3 and the output selection signal line Sel are made to have a low-level potential. Note that the photodetection reset signal line PR, the first charge transmission control signal line TX1, the second charge transmission control signal line TX2, the first data input selection signal line Select1, and the second data input selection signal line Select2 hold the low-level potential.

In this manner, the photodetector circuit selection operation is completed.

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Further, from when the negative input terminal (the terminal IN-) of the differential amplifier 140 holds VB (the data of the optical data signal in the capture period) and the positive input terminal (the terminal IN+) of the differential amplifier 140 holds VC (the data of the optical data signal in the reset period), the potential of the output terminal (the terminal Out) of the differential amplifier 140 is VC-VB. For example, in a method for driving the photodetector illustrated in FIG. 4A, the potential of the output terminal (the terminal Out) of the differential amplifier 140 is determined in the time T20 (the second selection operation completion time).

The above is the example of the method for driving the photodetector illustrated in FIG. 4A.

As described with reference to FIGS. 2A and 2B, FIGS. 3A and 3B, and FIGS. 4A and 4B, in an example of the photodetector of this embodiment, difference data of data of the optical data signal in a reset mode and data of the optical data signal in a capture mode is generated. The two data include common noises in the same frame period. For example, in the case where data of the optical data signal in a reset mode is $V_r + V_z$ (V_z is the amount of change due to noise) and data of the optical data signal in a capture mode is $V_r + V_z - V_p$ or $V_r + V_z + V_p$, the difference data of the two data is generated, and the difference data is V_p or $-V_p$, which does not depend on V_z . Since noise components can be removed from the data to be generated by generating difference data, adverse effects of noise can be suppressed.

In one example of the photodetector of this embodiment, the plurality of charge transmission control transistors in which different signals are input to gates are used for each photoelectric conversion element, whereby difference data is generated on the basis of one optical data signal; accordingly, the number of elements of the photodetector circuit can be small. Therefore, the aperture ratio of the photodetector can be increased. Since two optical data signals are analog signals, difference data of the data of the two analog signals can be generated. In comparison with the case where difference data of data of digital signals is generated, the accuracy of removing the amount of change due to noise from the generated data can be higher.

In one example of the photodetector of this embodiment, a transistor with low off-state current is used as a charge transmission control transistor, whereby leakage current of the transistor can be low; therefore, a reset potential holding capacitance can be small. Accordingly, the area of the photoelectric conversion element can be larger. As a result, adverse effects of noise can be suppressed.

Embodiment 3

In this embodiment, an example of a photodetector will be described.

First, a configuration example of the photodetector of this embodiment will be described with reference to FIG. 5. FIG. 5 is a block diagram illustrating a configuration example of photodetector of this embodiment.

A photodetector illustrated in FIG. 5 is an input device which can input data with light.

The photodetector illustrated in FIG. 5 includes a photodetection portion (also referred to as Photo) 401, a control unit (also referred to as Ctl) 402, and a data processing unit (also referred to as DataP) 403.

In addition, the photodetector illustrated in FIG. 5 includes a photodetection driver circuit (also referred to as PSDrv) 411, a plurality of photodetector circuits (also referred to as PS) 412, a data input selection circuit (also referred to as SCtl) 413, a difference data generation circuit (also referred to as

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Dif) **414**, a read circuit (also referred to as Read) **415**, an A/D converter circuit (also referred to as A/D) **416**, a photodetection control circuit **421**, and an image processing circuit (also referred to as ImgP) **431**.

The photodetection driver circuit **411** is provided in the photodetection portion **401**. The photodetection driver circuit **411** is a circuit for controlling a photodetection operation.

The photodetector driving circuit **411** outputs at least a photodetection reset signal, a charge accumulation control signal, and an output selection signal which are pulse signals.

The photodetection driver circuit **411** has, for example, at least three shift registers. In this case, the photodetection driver circuit **411** outputs a pulse signal from the first shift register in order to output the photodetection reset signal, outputs a pulse signal from the second shift register in order to output the charge accumulation control signal, and outputs a pulse signal from the third shift register in order to output an output selection signal.

The plurality of photodetector circuits **412** are provided in the row and column directions in a pixel portion Pix of the photodetection portion **401**. Note that one or more photodetector circuits **412** form one pixel in the photodetector shown in FIG. 5. The photodetector circuit **412** generates optical data having a potential of a value corresponding to the illuminance of incident light.

A photodetector circuit in the photodetector in Embodiment 1 can be used as the photodetector circuit **412**. The photodetector circuit **412** may be provided with a cooling unit, which suppresses occurrence of noise due to heat.

Note that it is also possible to generate the data of a full-color image signal by providing photodetector circuits receiving red light, photodetector circuits receiving green light, and photodetector circuits receiving blue light as the plurality of photodetector circuits **412**, generating an optical data signal by these photodetector circuits, and combining the generated data of the optical data signal. In addition to the above-described photodetection circuits, one or more photodetection circuits receiving light of the following colors: cyan, magenta, and yellow may be provided. By providing one or more photodetection circuits receiving light of one or more the following colors: cyan, magenta, and yellow, the number of colors that can be represented in a displayed image based on generated image signals can be increased. For example, by providing a coloring layer, which transmits light of a particular color, in a photodetector circuit and letting light enter the photodetector circuit through the coloring layer, the optical data signal that is a potential having a value corresponding to the illuminance of light of a particular color can be generated.

The data input selection circuit **413** is provided for each column of the photodetector circuits of the pixel portion. An optical data signal is input from the photodetector circuits **412** in the column to the data input selection circuit **413**. The data input selection circuit in the photodetector in Embodiment 1 can be used as the data input selection circuit **413**.

The difference data generation circuit **414** is provided for each column to be electrically connected to the data input selection circuits **413** in the column of the pixel portion. The difference data generation circuit in Embodiment 1 can be used as the difference data generation circuit **414**.

The read circuit **415** is provided in the photodetection portion **401**. The read circuit **415** has a function of reading optical data from the photodetector circuit. The read circuit **415** is electrically connected to the output terminal of each difference data generation circuit **414**.

The read circuit **415** includes, for example, a selection circuit. For example, the selection circuit includes a transistor

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and can read data of an optical data signal when the optical data signal is input to the selection circuit in accordance with the behavior of the transistor.

The A/D converter circuit **416** is provided in the photodetection portion **401**. The A/D converter circuit **416** has a function of converting analog data which is input from the read circuit **415** into digital data. Note that the A/D converter circuit **416** is not necessarily provided in the photodetection portion **401**.

The photodetection control circuit **421** is provided in the control unit **402**. The photodetection control circuit **421** has a function of controlling operations of a circuit for a photodetection operation.

The image processing circuit **431** is provided in the data processing unit **403**. The image processing circuit **431** has a function of generating image data with the use of an optical data signal generated in the photodetection portion.

Note that the pixel portion may include a display circuit. With such a structure, the photodetector can have a function of a touch panel.

Next, an example of a method for driving the photodetector in FIG. 5 will be described.

The photodetector illustrated in FIG. 5 generates an optical data signal in the photodetector circuit **412**. When image capture is implemented in the plurality of photodetector circuits **412** by a global shutter system, distortion of an image to be generated can be suppressed.

Further, with the use of the data input selection circuit **413**, an optical data signal of the photodetector circuit **412** in a reset mode is input to a first input terminal of the difference data generation circuit **414**, and an optical data signal of the photodetector circuit **412** in a capture mode is input to a second input terminal of the difference data generation circuit **414**.

The difference data generation circuit **414** generates difference data.

The difference data is read by the read circuit **415**.

The read difference data is converted to digital data by the A/D converter circuit **416**. The data is used, for example, by the image processing circuit **431** or the like for a predetermined treatment.

The above are the descriptions of the examples of the methods for driving the photodetector shown in FIG. 5.

As described with reference to FIG. 5, in one example of the photodetector of this embodiment, since difference data is generated for each column, the number of the difference data generation circuits can accordingly be reduced.

In one example of the photodetector of this embodiment, digital difference data is generated by converting analog difference data, whereby the accuracy of removing the amount of change due to noise from the generated data can be higher. Thus, the quality of a captured image can be improved.

Embodiment 4

In this embodiment, examples of electronic devices each including the photodetector described in the above embodiment will be described.

Structure examples of the electronic device of this embodiment will be described with reference to FIGS. 6A and 6B and FIGS. 7A and 7B.

An electronic device illustrated in FIG. 6A is a digital camera. The digital camera illustrated in FIG. 6A includes a housing **1001a**, a lens **1002a**, a shutter button **1003**, a power button **1004**, and a flashlight **1005**.

Further, the housing **1001a** includes a photodetector of the above embodiments. With this structure, incident light is

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detected by the photodetector through the lens **1002a** by pushing the shutter button **1003**, so that an image can be taken, for example.

An electronic device illustrated in FIG. **6B** is a video camera. The video camera illustrated in FIG. **6B** includes a housing **1001b**, a lens **1002b**, and a display portion **1006**.

Further, the housing **1001b** includes a photodetector of the above embodiments. With this structure, incident light is detected by the photodetector through the lens **1002b**, so that an image can be taken, for example.

An electronic device illustrated in FIGS. **7A** and **7B** is an example of a folding information terminal. FIG. **7A** is a schematic external view and FIG. **7B** is a block diagram.

The electronic device illustrated in FIGS. **7A** and **7B** includes, as illustrated in FIG. **7A**, a housing **1600a**, a housing **1600b**, a panel **1601a**, a panel **1601b**, a hinge **1602**, a button **1603**, a connection terminal **1604**, a recording medium insertion portion **1605**, and a lens **1608**. The electronic device illustrated in FIGS. **7A** and **7B** also includes, as illustrated in FIG. **7B**, a power source portion **1611**, a wireless communication portion **1612**, an arithmetic portion **1613**, an audio portion **1614**, a panel portion **1615**, and a capture portion **1616**.

The panel **1601a** is provided for the housing **1600a**.

The panel **1601b** is provided for the housing **1600b**. The housing **1600b** is connected to the housing **1600a** with the hinge **1602**.

The panel **1601a** and the panel **1601b** each have a function of a display panel. For example, the panel **1601a** and the panel **1601b** may display different images or one image.

In addition, one or both of the panel **1601a** and the panel **1601b** may have a faction of a touch panel. In this case, for example, input operations may be performed by touching a keyboard image which is displayed on one or both of the panel **1601a** and the panel **1601b**, with a finger **1609** or the like. One or both of the panel **1601a** and the panel **1601b** may be formed by stacking a display panel and a touch panel. One or both of the panel **1601a** and the panel **1601b** may be formed using an input-output panel including a display circuit and a photodetector circuit.

Since the electronic device illustrated in FIG. **7A** has the hinge **1602**, the housing **1600a** or the housing **1600b** can be moved to overlap the housing **1600a** with the housing **1600b**, for example; that is, the electronic device can fold.

The button **1603** is provided for the housing **1600b**. Further or alternatively, the housing **1600a** may be provided with the button **1603**. Alternatively, the plurality of buttons **1603** may be provided for one or both of the housing **1600a** and the housing **1600b**. For example, when a power button is provided as the button **1603**, the electronic device can be turned on or off by pressing the button **1603**.

The connection terminal **1604** is provided for the housing **1600a**. Alternatively, the housing **1600b** may be provided with the connection terminal **1604**. Alternatively, the plurality of connection terminal **1604** may be provided for one or both of the housing **1600a** and the housing **1600b**. For example, a personal computer is connected to the electronic device through the connection terminal **1604** so that data stored in the electronic device may be rewritten with the personal computer.

The recording medium insertion portion **1605** is provided for the housing **1600a**. Alternatively, the housing **1600b** may be provided with the recording medium insertion portion **1605**. Alternatively, the plurality of recording medium insertion portions **1605** may be provided for one or both of the housing **1600a** and the housing **1600b**. For example, a card-type recording medium is inserted into the recording medium

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insertion portion so that data can be read to the electronic device from the card-type recording medium or data stored in the electronic device can be written to the card-type recording medium.

The lens **1608** is provided for the housing **1600b**. Further or alternatively, the housing **1600a** may be provided with the lens **1608**. The plurality of lenses **1608** may be provided for one or both of the housing **1600a** and the housing **1600b**.

Further, the housing **1600a** and the housing **1600b** each include the photodetector of the above embodiment. The photodetector detects light coming through the lens **1608**, whereby still images and moving images can be taken. Further, the panel **1601a** and the panel **1601b** may be each provided with the photodetector of the above embodiment. As the photodetector, the photodetector in Embodiment 2 can be used, for example.

The power source portion **1611** has a function of controlling supply of power for driving the electronic device. For example, power is supplied from the power source portion **1611** to the wireless communication portion **1612**, the arithmetic portion **1613**, the audio portion **1614**, and the panel portion **1615**. The power source portion **1611** is provided with a power storage device, for example. The power storage device is included in one or both of the housing **1600a** and the housing **1600b**. Note that a power source circuit with a function of generating a power source voltage for driving the electronic device may be provided for the power source portion **1611**. In that case, a power source voltage is generated in the power source circuit by using power supplied from the power storage device. Further or alternatively, the power source portion **1611** may be connected to a commercial power supply.

The wireless communication portion **1612** has a function of transmitting and receiving a radio wave. For example, the wireless communication portion **1612** includes an antenna, a demodulation circuit, a modulation circuit, and the like. In this case, for example, data is exchanged by the antenna by transmission/reception of radio waves to/from the outside. Note that the wireless communication portion **1612** may be provided with a plurality of antennas.

The arithmetic portion **1613** has a function of performing arithmetic processing in accordance with an instruction signal input from the wireless communication portion **1612**, the audio portion **1614**, the panel portion **1615**, and the capture portion **1616**, for example. For example, the arithmetic portion **1613** includes CPU, a logic circuit, a memory circuit, and the like.

The audio portion **1614** has a function of controlling input and output of sounds that are audio data. For example, the audio portion **1614** includes a speaker and a microphone.

For example, one or both of the housing **1600a** and the housing **1600b** include the power source portion **1611**, the wireless communication portion **1612**, the arithmetic portion **1613**, and the audio portion **1614**.

The panel portion **1615** has a function of controlling operations of the panel **1601a** (also referred to as panel A) and the panel **1601b** (also referred to as panel B). Note that the panel portion **1615** may be provided with a driver circuit for controlling driving of the panel **1601a** and the panel **1601b** to control the operations of the panel **1601a** and the panel **1601b**.

The capture portion **1616** includes a photodetector **1610**. The capture portion **1616** has a function of controlling operation of the photodetector **1610**.

Note that one or more of the power source portion **1611**, the wireless communication portion **1612**, the arithmetic portion **1613**, the audio portion **1614**, the panel portion **1615**, and the capture portion **1616** may be provided with a control circuit

so that the operation can be controlled by the control circuit. A control circuit may be provided for the arithmetic portion 1613 to control operation of one or more of the power source portion 1611, the wireless communication portion 1612, the audio portion 1614, the panel portion 1615, and the capture portion 1616.

One or more of the power source portion 1611, the wireless communication portion 1612, the audio portion 1614, the panel portion 1615, and the capture portion 1616 may be provided with a memory circuit so that needed data is stored in the memory circuit in operation. Thus, operation rate can be increased.

The electronic device illustrated in FIGS. 7A and 7B can be supplied with power from a commercial power supply and also use power accumulated in a power storage device. Accordingly, even when there is no supply of power from the commercial power supply because of a power failure or the like, for example, the electronic device can be driven by using the power storage device as a power source.

With the structure illustrated in FIGS. 7A and 7B, the electronic device illustrated in FIGS. 7A and 7B can have a function of one or more of a telephone set, an e-book reader, a personal computer, and a game machine, for example.

As described with reference to FIGS. 6A and 6B and FIGS. 7A and 7B, in the examples of the electronic devices according to this embodiment, the photodetectors in the above embodiments can be used. With the use of the photodetector, an electronic device which is capable of capturing an image with high accuracy can be provided.

Example 1

In this example, a photodetector that was actually fabricated will be described.

A photodetector in this example includes a plurality of photodetector circuits that are arranged in row and column directions, a plurality of difference data generation circuits to which optical data signals of photodetector circuits in each column are input, and a plurality of data input selection circuits for controlling the potential of an input terminal of each difference data generation circuit. Note that the number of rows of the photodetector circuits is 150.

Further, the circuit configuration of the photodetector including photodetector circuits in the n-th row (n is a natural number of two or more) will be described with reference to FIGS. 8A and 8B.

The photodetector illustrated in FIG. 8A includes the photodetector circuit PS, the difference data generation circuit Dif, the data input selection circuit DIS, a column bus CB1, a column bus CB2, a field-effect transistor 9028_1, and a field-effect transistor 9028_2.

The photodetector circuit PS includes a photodiode 9010, field-effect transistors 9021 to 9024, a capacitor 9031, the capacitor 9032, a field-effect transistor 9025_1, and a field-effect transistor 9025_2.

A cathode of the photodiode 9010 is connected to the photodetection reset signal line PR.

One of a source and a drain of the field-effect transistor 9021 is connected to an anode of the photodiode 9010. A gate of the field-effect transistor 9021 is connected to the first charge transmission control signal line TX1.

One of a source and a drain of the field-effect transistor 9022 is connected to the anode of the photodiode 9010. A gate of the field-effect transistor 9022 is connected to the second charge transmission control signal line TX2.

One of a pair of electrodes of the capacitor 9031 is connected to the other of the source and the drain of the field-

effect transistor 9021. A ground potential is supplied to the other of the pair of electrodes of the capacitor 9031.

One of a pair of electrodes of the capacitor 9032 is connected to the other of the source and the drain of the field-effect transistor 9022. A ground potential is supplied to the other of the pair of electrodes of the capacitor 9032.

One of a source and a drain of the field-effect transistor 9023 is connected to the other of the source and the drain of the field-effect transistor 9021. A gate of the field-effect transistor 9023 is connected to the data input selection signal line Select1[n].

A potential Vpi is supplied to one of a source and a drain of the field-effect transistor 9024. A gate of the field-effect transistor 9024 is connected to the other of the source and the drain of the field-effect transistor 9022 and the other of the source and the drain of the field-effect transistor 9023.

One of a source and a drain of the field-effect transistor 9025_1 is connected to the other of the source and the drain of the field-effect transistor 9024. The other of the source and the drain of the field-effect transistor 9025_1 is connected to the column bus CB1. A gate of the field-effect transistor 9025_1 is connected to the data input selection signal line Select1[n].

One of a source and a drain of the field-effect transistor 9025_2 is connected to the other of the source and the drain of the field-effect transistor 9024. The other of the source and the drain of the field-effect transistor 9025_2 is connected to the column bus CB2. A gate of the field-effect transistor 9025_2 is connected to the data input selection signal line Select2[n].

The difference data generation circuit Dif includes a differential amplifier (also referred to as Differential Amp) 9040.

The data input selection circuit DIS includes a field-effect transistor 9026 and a field-effect transistor 9027.

One of a source and a drain of the field-effect transistor 9026 is connected to the column bus CB1. The other of the source and the drain of the field-effect transistor 9026 is electrically connected to a negative input terminal of the differential amplifier 9040 in the difference data generation circuit Dif. A gate of the field-effect transistor 9026 is connected to a data input selection signal line SelectP.

One of a source and a drain of the field-effect transistor 9027 is connected to the column bus CB2. The other of the source and the drain of the field-effect transistor 9027 is electrically connected to a positive input terminal of the differential amplifier 9040 in the difference data generation circuit Dif. A gate of the field-effect transistor 9027 is connected to a data input selection signal line SelectD.

A potential Vp0 is supplied to one of a source and a drain of the field-effect transistor 9028_1. The other of the source and the drain of the field-effect transistor 9028_1 is connected to the column bus CB1. A gate of the field-effect transistor 9028_1 is connected to a voltage supply line Bias.

The potential Vp0 is supplied to one of a source and a drain of the field-effect transistor 9028_2. The other of the source and the drain of the field-effect transistor 9028_2 is connected to the column bus CB2. A gate of the field-effect transistor 9028_2 is connected to the voltage supply line Bias.

A capacitor 9033 and a capacitor 9034 are parasitic capacitance.

Next, a method for driving the photodetector of this example will be described with reference to a timing chart in FIG. 8B.

As illustrated in FIG. 8B, a pulse of the photodetection reset signal line PR, a pulse of the first charge transmission control signal line TX1, and a pulse of the second charge transmission control signal line TX2 are input so that the photodetector circuit PS becomes a reset mode.

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Next, the field-effect transistor **9022** is turned off by the pulse of the second charge transmission control signal line TX2, so that charge of the node FD2 is held.

The field-effect transistor **9021** is turned off by the pulse of the first charge transmission control signal line TX1, so that charge of the node FD1 is held.

The above operation is performed on every photodetector circuit.

Next, a pulse of a data input selection signal line Select2[K (K is a natural number of 1 or more and 150 or less)] is input, whereby an optical data signal is output to the column bus CB2. Data of the optical data signal is data when the photodetector circuit PS is in a reset mode.

Then, a pulse of a data input selection signal line Select1[K (K is a natural number of 1 or more and 150 or less)] is input, whereby an optical data signal is output to the column bus CB1. Data of the optical data signal is data when the photodetector circuit PS is in a capture mode.

By a pulse of the data input selection signal line SelectP, an optical data signal input through the column bus CB1 is output to the differential amplifier **9040** in the difference data generation circuit Dif. By a pulse of the data input selection signal line SelectD, an optical data signal input through the column bus CB2 is output to the differential amplifier **9040** in the difference data generation circuit Dif.

The differential amplifier **9040** in the difference data generation circuit Dif generates difference data of data of the optical data signal input through the column bus CB1 and data of the optical data signal input through the column bus CB2 and outputs the difference data to an A/D converter as an output signal.

The above is the method for driving the photodetector in this example.

Next, a structure of the photodetector circuit in the photodetector illustrated in FIG. 8A will be described with reference to FIGS. 9A and 9B. FIG. 9A is a schematic plan view and FIG. 9B is a schematic cross-sectional view taken along line A-B in FIG. 9A. Note that the components illustrated in FIGS. 9A and 9B include those having sizes different from the actual sizes. For convenience, in FIG. 9B, part of cross section along line A-B of FIG. 9A is not shown.

The photodetector circuit illustrated in FIGS. 9A and 9B includes the photodiode **9010**, the field-effect transistor **9021**, the field-effect transistor **9022**, the capacitor **9031**, the capacitor **9032**, the field-effect transistor **9023**, the field-effect transistor **9024**, the field-effect transistor **9025_1**, and the field-effect transistor **9025_2**.

The field-effect transistors **9021** to **9023** are n-channel transistors each including an oxide semiconductor layer in which a channel is formed. The field-effect transistor **9024**, the field-effect transistor **9025_1**, and the field-effect transistor **9025_2** are n-channel transistors each including a silicon semiconductor layer in which a channel is formed. The photodiode **9010** is a lateral PIN junction diode including a silicon semiconductor layer.

As illustrated in FIG. 9B, the photodetector circuit includes a semiconductor layer **9513a**, a semiconductor layer **9513b**, an insulating layer **9516**, a conductive layer **9517**, an insulating layer **9518**, an oxide semiconductor layer **9519**, conductive layers **9520a** to **9520e**, an insulating layer **9521**, conductive layers **9522a** to **9522c**, an insulating layer **9523**, and a conductive layer **9524**.

The semiconductor layer **9513a** and the semiconductor layer **9513b** are provided over a substrate **9500** with an insulating layer **9502** laid therebetween.

A single crystal silicon substrate was used as the substrate **9500**.

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As the insulating layer **9502**, a stacked layer of a 400-nm-thick silicon oxide layer, a 50-nm-thick silicon nitride oxide layer, and a 100-nm-thick silicon oxide layer was used.

The semiconductor layer **9513a** includes an N-type region **9514a** and a P-type region **9515**.

The semiconductor layer **9513b** includes an N-type region **9514b** and an N-type region **9514c**.

As the semiconductor layer **9513b**, a 130-nm-thick single crystal silicon layer was used. As the semiconductor layer **9513a**, a 60-nm-thick single crystal silicon layer which is formed by etching of a 130-nm-thick single crystal silicon layer was used.

The insulating layer **9516** is provided over the semiconductor layer **9513a** and the semiconductor layer **9513b**. A 20-nm-thick silicon oxide layer was used as the insulating layer **9516**.

The conductive layer **9517** is formed over the semiconductor layer **9513b** with the insulating layer **9516** laid therebetween. As the conductive layer **9517**, a stacked layer of a 30-nm-thick tantalum nitride layer and a 170-nm-thick tungsten layer was used.

The insulating layer **9518** is provided over the insulating layer **9516** and the conductive layer **9517**. As the insulating layer **9518**, a stacked layer of a 50-nm-thick silicon oxynitride layer and a 500-nm-thick silicon oxide layer was used.

The oxide semiconductor layer **9519** is provided over the insulating layer **9518**. As the oxide semiconductor layer **9519**, a 20-nm-thick IGZO layer was used.

The conductive layer **9520a** is in contact with the N-type region **9514a** of the semiconductor layer **9513a** through an opening penetrating the insulating layer **9516** and the insulating layer **9518**.

The conductive layer **9520b** is in contact with the P-type region **9515** of the semiconductor layer **9513a** through an opening penetrating the insulating layer **9516** and the insulating layer **9518**. The conductive layer **9520b** is also in contact with the oxide semiconductor layer **9519**.

The conductive layer **9520c** is in contact with the oxide semiconductor layer **9519**.

The conductive layer **9520d** is in contact with the N-type region **9514b** of the semiconductor layer **9513b** through an opening penetrating the insulating layer **9516** and the insulating layer **9518**.

The conductive layer **9520e** is in contact with the N-type region **9514c** of the semiconductor layer **9513b** through an opening penetrating the insulating layer **9516** and the insulating layer **9518**.

As each of the conductive layers **9520a** to **9520e**, a 100-nm-thick tungsten layer was used.

The insulating layer **9521** is provided over the insulating layer **9518**, the oxide semiconductor layer **9519**, and the conductive layers **9520a** to **9520e**.

As the insulating layer **9521**, a 30-nm-thick silicon oxynitride layer was used.

The conductive layer **9522a** is provided over the oxide semiconductor layer **9519** with the insulating layer **9521** laid therebetween.

The conductive layer **9522b** overlaps with the conductive layer **9520c** with the insulating layer **9521** laid therebetween.

The conductive layer **9522c** is provided over the insulating layer **9521**.

As each of the conductive layers **9522a** to **9522c**, a stacked layer of a 30-nm-thick tantalum nitride layer and a 135-nm-thick tungsten layer was used.

The insulating layer **9523** is provided over the insulating layer **9521** and the conductive layers **9522a** to **9522c**.

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As the insulating layer **9523**, a stacked layer of a 50-nm-thick aluminum oxide layer and a 300-nm-thick silicon oxynitride layer was used.

The conductive layer **9524** is in contact with the conductive layer **9522b** through an opening penetrating the insulating layer **9523**.

As the conductive layer **9524**, a stacked layer of a 50-nm-thick titanium layer, a 200-nm-thick aluminum layer, and a 50-nm-thick titanium layer was used.

A field-effect transistor including an oxide semiconductor layer (e.g., the field-effect transistor **9021**) is provided over the photodiode **9010** and a field-effect transistor including a silicon semiconductor layer (e.g., the field-effect transistor **9024**). Thus, an increase in area can be prevented.

The above is description of the structure of the photodetector circuit in the photodetector illustrated in FIG. **8A**.

As described with reference to FIGS. **8A** and **8B** and FIGS. **9A** and **9B**, in the photodetector of this example, the photodetector of the above embodiments was able to be formed, in which a photodiode and a field-effect transistor are formed using a silicon semiconductor layer and further a field-effect transistor is formed using an oxide semiconductor layer over the silicon semiconductor layer.

EXPLANATION OF REFERENCE

110: photoelectric conversion element; **121**: field-effect transistor; **122**: field-effect transistor; **123**: field-effect transistor; **124**: field-effect transistor; **125**: field-effect transistor; **125_1**: field-effect transistor; **125_2**: field-effect transistor; **126**: field-effect transistor; **127**: field-effect transistor; **128**: field-effect transistor; **131**: capacitor; **132**: capacitor; **140**: differential amplifier; **401**: photodetection portion; **402**: control unit; **403**: data processing unit; **411**: photodetection driver circuit; **412**: photodetector circuit; **413**: data input selection circuit; **414**: difference data generation circuit; **415**: read circuit; **416**: A/D converter circuit; **421**: photodetection control circuit; **431**: image processing circuit; **1001a**: housing; **1001b**: housing; **1002a**: lens; **1002b**: lens; **1003**: shutter button; **1004**: power button; **1005**: flashlight; **1006**: display portion; **1600a**: housing; **1600b**: housing; **1601a**: panel; **1601b**: panel; **1602**: hinge; **1603**: button; **1604**: connection terminal; **1605**: recording medium insertion portion; **1608**: lens; **1609**: finger; **1610**: photodetector; **1611**: power source portion; **1612**: wireless communication portion; **1613**: arithmetic portion; **1614**: audio portion; **1615**: panel portion; **1616**: capture portion; **9010**: photodiode; **9021**: field-effect transistor; **9022**: field-effect transistor; **9023**: field-effect transistor; **9024**: field-effect transistor; **9025_1**: field-effect transistor; **9025_2**: field-effect transistor; **9026**: field-effect transistor; **9027**: field-effect transistor; **9028_1**: field-effect transistor; **9028_2**: field-effect transistor; **9031**: capacitor; **9032**: capacitor; **9033**: capacitor; **9034**: capacitor; **9040**: differential amplifier; **9500**: substrate; **9502**: insulating layer; **9513a**: semiconductor layer; **9513b**: semiconductor layer; **9514a**: N-type region; **9514b**: N-type region; **9514c**: N-type region; **9515**: P-type region; **9516**: insulating layer; **9517**: conductive layer; **9518**: insulating layer; **9519**: oxide semiconductor layer; **9520a**: conductive layer; **9520b**: conductive layer; **9520c**: conductive layer; **9520d**: conductive layer; **9520e**: conductive layer; **9521**: insulating layer; **9522a**: conductive layer; **9522b**: conductive layer; **9522c**: conductive layer; **9523**: insulating layer; **9524**: conductive layer

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This application is based on Japanese Patent Application serial no. 2011-206899 filed with Japan Patent Office on Sep. 22, 2011, the entire contents of which are hereby incorporated by reference.

The invention claimed is:

1. A photodetector comprising:

a photoelectric conversion element;
a difference data generation circuit comprising a differential amplifier;
a data bus;
a switch electrically connected to the data bus;
a first transistor;
a second transistor;
a third transistor;
a fourth transistor; and
a data input selection circuit comprising:
a fifth transistor; and
a sixth transistor,
wherein one of a source and a drain of the first transistor is electrically connected to the photoelectric conversion element,
wherein one of a source and a drain of the second transistor is electrically connected to the photoelectric conversion element,
wherein the other of the source and the drain of the first transistor is electrically connected to the other of the source and the drain of the second transistor,
wherein the other of the source and the drain of the second transistor is electrically connected to a gate of the third transistor,
wherein one of a source and a drain of the third transistor is electrically connected to one of a source and a drain of the fourth transistor,
wherein the other of the source and the drain of the fourth transistor is electrically connected to the data bus,
wherein one of a source and a drain of the fifth transistor is electrically connected to the data bus,
wherein one of a source and a drain of the sixth transistor is electrically connected to the data bus,
wherein the other of the source and the drain of the fifth transistor is electrically connected to a first input terminal of the differential amplifier, and
wherein the other of the source and the drain of the sixth transistor is electrically connected to a second input terminal of the differential amplifier.

2. The photodetector according to claim 1, further comprising:

a first capacitor;
a second capacitor; and
a seventh transistor,
wherein an electrode of the first capacitor is electrically connected to the other of the source and the drain of the first transistor,
wherein an electrode of the second capacitor is electrically connected to the other of the source and the drain of the second transistor, and
wherein the other of the source and the drain of the first transistor is electrically connected to the other of the source and the drain of the second transistor through the seventh transistor.

3. The photodetector according to claim 1, further comprising:

a first capacitor;
a second capacitor; and
a seventh transistor,

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wherein an electrode of the first capacitor is electrically connected to the other of the source and the drain of the first transistor,

wherein one of a source and a drain of the seventh transistor is electrically connected to the second input terminal of the differential amplifier, and

wherein the other of the source and the drain of the seventh transistor is electrically connected to an electrode of the second capacitor.

4. The photodetector according to claim 1,

wherein the first transistor comprises an oxide semiconductor layer comprising a channel formation region.

5. A photodetector comprising:

a photoelectric conversion element;

a difference data generation circuit comprising a differential amplifier;

a first data bus;

a second data bus;

a first switch electrically connected to the first data bus;

a second switch electrically connected to the second data bus;

a first transistor;

a second transistor;

a third transistor;

a fourth transistor;

a data input selection circuit comprising:

a fifth transistor; and

a sixth transistor; and

a seventh transistor,

wherein one of a source and a drain of the first transistor is electrically connected to the photoelectric conversion element,

wherein one of a source and a drain of the second transistor is electrically connected to the photoelectric conversion element,

wherein the other of the source and the drain of the first transistor is electrically connected to the other of the source and the drain of the second transistor,

wherein the other of the source and the drain of the second transistor is electrically connected to a gate of the third transistor,

wherein one of a source and a drain of the third transistor is electrically connected to one of a source and a drain of the fourth transistor,

wherein the other of the source and the drain of the fourth transistor is electrically connected to the first data bus,

wherein one of a source and a drain of the fifth transistor is electrically connected to the first data bus,

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wherein one of a source and a drain of the sixth transistor is electrically connected to the second data bus,

wherein the other of the source and the drain of the fifth transistor is electrically connected to a first input terminal of the differential amplifier,

wherein the other of the source and the drain of the sixth transistor is electrically connected to a second input terminal of the differential amplifier,

wherein one of a source and a drain of the seventh transistor is electrically connected to the one of the source and the drain of the third transistor, and

wherein the other of the source and the drain of the seventh transistor is electrically connected to the second data bus.

6. The photodetector according to claim 5, further comprising:

a first capacitor;

a second capacitor; and

an eighth transistor,

wherein an electrode of the first capacitor is electrically connected to the other of the source and the drain of the first transistor,

wherein an electrode of the second capacitor is electrically connected to the other of the source and the drain of the second transistor, and

wherein the other of the source and the drain of the first transistor is electrically connected to the other of the source and the drain of the second transistor through the eighth transistor.

7. The photodetector according to claim 5, further comprising:

a first capacitor;

a second capacitor; and

an eighth transistor,

wherein an electrode of the first capacitor is electrically connected to the other of the source and the drain of the first transistor,

wherein one of a source and a drain of the eighth transistor is electrically connected to the second input terminal of the differential amplifier, and

wherein the other of the source and the drain of the eighth transistor is electrically connected to an electrode of the second capacitor.

8. The photodetector according to claim 5,

wherein the first transistor comprises an oxide semiconductor layer comprising a channel formation region.

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